SD11
.U5963
No. 13

EVALUATION OF SPRUCE AND FIR MORTALITY IN THE SOUTHERN APPALACHIAN MOUNTAINS

Protection Report R8-PR 13 October, 1988

Standing dead spruce and fir on the Black Mountains.

EVALUATION OF SPRUCE AND FIR MORTALITY IN THE SOUTHERN APPALACHIAN MOUNTAINS

BY

Charles W. Dull, Entomologist, Atlanta, GA
James D. Ward, Entomologist, Asheville, NC
H. Daniel Brown, Pathologist, Atlanta, GA
George W. Ryan, Statistician, Atlanta, GA
William H. Clerke, Remote Sensing Specialist, Atlanta, GA
Robert J. Uhler, Computer Specialist, Atlanta, GA

The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Property of
National FS Library
USDA Forest Service
240 W Prospect Rd
Fort Collins CO 80526

Cover photo-Standing dead spruce and fir on Clingman's Dome, Great Smoky Mountains National Park.

TABLE OF CONTENTS

Page

List of Tables iv
List of Figures v

ACKNOWLEDGEMENTS ix

EXECUTIVE SUMMARY 1

INTRODUCTION 3
The Spruce-Fir Ecotype in the Southern Appalachian Mountains 4
Current Threats to the Spruce-Fir Ecosystem in the Southern Appalachian Mountains 5

OBJECTIVES 9

METHODS 11
Aerial Photography Acquisition and Annotation 11
Photo Interpretation 11
Sampling Methods 12
Stratification and Selection of Aerial Sample Plots 12
Stratification and Selection of Ground Sample Plots 12
Implementation of the Geographic Database 13
Map Digitizing and Data Entry 14
GIS Data Analysis and Map Production 15
Computer System Configuration 16
Quality Assurance 16

RESULTS AND DISCUSSION 19
Aerial Photography Acquisition and Annotation 19
Aerial Photographic Interpretation 19
Analysis of Data and Review of Cartographic Products 21
Combined Results for Six Geographic Areas 21
Black Mountains 29
Great Smoky Mountains National Park 39
Roan Mountain 49
Balsam Mountains 59
Grandfather Mountain 67
Mount Rogers and White Top Mountain 68

CONCLUSIONS 85
LITERATURE CITED 87

LIST OF TABLES

Table Number		Page
1.	Number of aerial photo sample plots, by geographic region	12
2.	Number of ground sample plots, by geographic region	13
3.	Spruce-fir mortality correlations for ground surveys versus areal photo interpretation	21
4.	Spruce and fir forest in the southern Appalachians, classified by level of mortality	23
5.	Spruce and fir mortality in the southern Appalachian mountains, stratified by elevation	25
6.	Results of ground survey for spruce-fir mortality in the southern Appalachian mountains by elevation stratum	27
7.	Spruce and fir forest type stand component in the southern Appalachian mountains, by elevation	28
8.	Total feet³ volume per acre, by condition and species for elevation–Black Mountains, NC	35
9.	Total feet³ volume per acre, by condition and species for elevation–Great Smoky Mountains National Park	47
10.	Total feet³ volume per acre, by condition and species for elevation–Roan Mountain	58
11.	Total feet³ volume per acre, by condition and species for elevation– Balsam Mountains, NC	66

LIST OF FIGURES

Figure Number — Page

1. Area of severe spruce-fir mortality in the southern Appalachian mountains 3
2. Spruce-fir forests occupy the highest peaks in North Carolina, Tennessee and Virginia 4
3. Balsam woolly adelgid (nymph) crawlers infesting the bole of Fraser fir 7
4. Color infrared aerial photograph showing delineation of spruce-fir forest type 20
5. Spruce-fir forest type in the southern Appalachian mountains 22
6. Spruce-fir forest type in the southern Appalachian mountains, classified by mortality 24
7. Spruce-fir type in the southern Appalachian mountains, by geographic area 24
8. Spruce-fir forest type, by State, in the southern Appalachian mountains 24
9. Spruce-fir mortality in the southern Appalachian mountains, classified by elevation 26
10. Mortality classification as a percent of area occupied, by elevation, in the southern Appalachian mountains 26
11. Mortality classification, by elevation, in relation to Fraser fir mortality and percent of stand component in the southern Appalachian mountains 29
12. Aerial view of Mount Mitchell, NC 29
13. Spruce-fir mortality, Black Mountains, NC 31
14. Area impacted by spruce-fir mortality on Black Mountains, NC 29
15. Spruce-fir mortality (acres), stratified by elevation on Mount Mitchell, NC 30
16. Percentages of spruce-fir mortality (percent), by elevation on the Black Mountains from ground survey 30
17. Spruce-fir stand component classified by elevation for the Black Mountains from ground survey 30

LIST OF FIGURES (continued)

Figure Number — Page

18. Black Mountains spruce-fir ownership distribution 34
19. Spruce-fir forest type, by ownership, on the Black Mountains. NC 33
20. Spruce-fir mortality by ownership, Black Mountains, NC 33
21. Timber volume by elevation, Black Mountains, NC 33
22. Timber volume by condition class, Black Mountains, NC 36
23. Fraser fir and red spruce volume by condition, Mount Mitchell 36
24. Mortality and stand history, Mount Mitchell 37
25. Spruce-fir mortality by disturbance, Mount Mitchell 36
26. Spruce-fir on Mount Mitchell,1960 versus 1984 38
27. Spruce-fir mortality 1960 versus 1984, Mount Mitchell 39
28. Study plot locations, Mount Mitchell 40
29. Spruce-fir mortality, Great Smoky Mountains National Park 43
30. Spruce-fir on the Great Smoky Mountains National Park classified by mortality 41
31. Spruce-fir type, Great Smoky Mountains National Park 45
32. Spruce-fir mortality stratified by elevation on the Great Smoky Mountains National Park 41
33. Spruce-fir mortality classified by elevation on the Great Smoky Mountains National Park 42
34. Spruce-fir stand component classified by elevation on the Great Smoky Mountains National Park from ground survey 42
35. Volume by elevation, Great Smoky Mountains National Park 48
36. Fraser fir and red spruce volume by condition on the Great Smoky Mountains National Park 48

LIST OF FIGURES (continued)

Figure Number Page

37. Timber volume, by condition class, Great Smoky Mountains National Park 48

38. Spruce-fir mortality, by disturbance, Great Smoky Mountains National Park 48

39. Study-plot locations, Great Smoky Mountains National Park 51

40. Spruce-fir mortality, Roan Mountain 53

41. Spruce-fir type (acres) on Roan Mountain, classified by mortality 49

42. Spruce-fir mortality, by elevation, Roan Mountain 55

43. Spruce-fir mortality (acres), stratified by elevation on Roan Mountain 50

44. Spruce-fir mortality, by elevation, on Roan Mountain from ground survey 50

45. Spruce-fir stand component, by elevation, for Roan Mountain 50

46. Timber volume, by elevation, Roan Mountain 57

47. Fraser fir and red spruce volume, by condition, on Roan Mountain 57

48. Timber volume, by condition class, Roan Mountain 57

49. Study plot locations, Roan Mountain 61

50. Spruce-fir mortality, Balsam Mountains, North Carolina 63

51. Spruce-fir type (acres) on the Balsam Mountains, classified by mortality 59

52. Spruce-fir mortality (acres), stratified by elevation, on the Balsam Mountains 60

53. Spruce-fir mortality percent, by elevation on the Balsam Mountains 60

54. Spruce-fir stand component classified by elevation for the Balsam Mountains 60

55. Spruce-fir ownership, Balsam Mountains 65

56. Spruce-fir mortality by ownership, Balsam Mountains 65

LIST OF FIGURES (continued)

Figure Number — Page

57. Timber volume, by elevation, Balsam Mountains 65

58. Fraser fir and red spruce volume, by condition, on the Balsam Mountains 67

59. Timber volume, by condition class, Balsam Mountains 67

60. Study plot locations, Balsam Mountains 69

61. Spruce-fir mortality, Grandfather Mountain 71

62. Spruce-fir type (acres), classified by mortality, on Grandfather Mountain 67

63. Spruce-fir mortality (acres), stratified by elevation, on Grandfather Mountain 68

64. Spruce-fir mortality, by elevation, Grandfather Mountain 73

65. Spruce-fir mortality, Mount Rogers and White Top Mountain 75

66. Spruce-fir forest type (acres), stratified by elevation, on Mount Rogers and White Top Mountain 68

67. Spruce-fir disturbance history, Mount Rogers 79

68. Balsam woolly adelgid infestations, Mount Rogers, 1986 81

69. Study-plot locations, Mount Rogers and White Top Mountain 83

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the following individuals and groups who have contributed to the successful completion of this project:

Doug Rubel, biological technician; construction of maps, data analysis, data capture, ground inventory, and overall database management.

Ken Kline, biological technician; ground inventory and data collection.

Mark Carter, biological technician; ground inventory and data collection.

Max Deaton, biological technician; ground inventory and data collection.

E. T. Wilson, photo interpreter (retired); assisted in the acquisition of the aerial photography, photo interpretation, and map transfer.

Robert Bassett, aerial photographer (retired); assisted in acquisition of aerial photography, photo interpretation, and map transfer.

Walter Salazar, aerial photographer; assisted in photo interpretation and map transfer; provided cover aerial photograph.

Dr. William Shane, Clemson University, and his graduate students; development of the aerial photo index.

Charlotte Pyle and **Tom Wentworth** contributed the disturbance-history data.

Chris Eagar, spruce-fir cooperative technical coordinator, Great Smoky Mountains National Park, submitted the location of the Spruce-Fir Cooperative intensive-study sites, contributed the spruce-fir forest type map on the Great Smoky Mountains National Park, and reviewed the manuscript.

Dr. Robert Bruck, North Carolina State University, School of Forestry, contributed locations of study sites established by North Carolina State University.

Dr. Shepherd Zedaker and **Niki Nicholas**; contributed the location of SARRMAC intensive study sites established on Mount Rogers and Mount Mitchell by Virginia Polytechnical Institute and State University School of Forestry.

W. M. Ciesla, Director, Forest Pest Management, Pacific Northwest Region, (formerly with FPM Methods Application Group, Ft. Collins, CO) for his review of the manuscript, and helpful suggestions throughout the project.

Louise Day for her untiring efforts in the development of this manuscript.

Darlene Lentini and **Linda Gresham**; assistance in the production of this manuscript.

Nona Huckabee, development of graphics and production of the manuscript.

Public Affairs Office, Technical Publications Staff, USDA Forest Service, Southern Region; assistance in the publication of this manuscript.

EXECUTIVE SUMMARY

Spruce-fir forests in the southern Appalachian mountains have received considerable attention recently because of large areas of concentrated mortality within this forest type. This project was undertaken to: (1) delineate the boundaries of the spruce-fir forest and map its range in the Southeast; (2) classify and map the amount of mortality (dead standing trees) occurring within the spruce-fir forest; and (3) analyze the relationship of this mortality to other geographic features.

Data were obtained from aerial photography and ground inventory. Photo interpretation was transferred to maps for analysis by a computerized geographic information system (GIS).

At the onset of this project, information on the boundaries of the spruce-fir forests and mortality within its range in the southern Appalachians was lacking. Complete stereo aerial photographic coverage was obtained over the Great Smoky Mountains National Park, Black Mountains, Balsam Mountains, Roan Mountain, Mount Rogers/White Top Mountain, and Grandfather Mountain.

Analysis of this information revealed that 65,752 acres (26,610 ha) of spruce-fir forests exist on higher elevation peaks throughout the Southeast. The spruce-fir forests form a series of island-like areas in southwestern Virginia, western North Carolina and eastern Tennessee.

The Great Smoky Mountains National Park contains 74% of the total spruce-fir type, followed by Black Mountains—11%; Balsam Mountains—lO%; Roan Mountain—2%; Mount Rogers/White Top—2%; and Grandfather Mountain—1%. Within these areas of spruce-fir forest, 24% of the total area was classified as severe mortality—(greater than 70% of the dominant and codominant standing trees dead)—heavy mortality occupying 6% of the type (30% to 70% of the standing trees dead), and 70% of the total area classified as light (less than 30% standing trees dead).

Further analysis of the percentage of standing dead timber revealed that severe mortality occupied a greater proportion of the area at higher elevations where the larger percentage of the stand component was Fraser fir. Conversely, red spruce occupied a greater percentage of the stand component at lower elevations, with a very small percentage of Fraser fir found at the lower elevations.

By studying ground data, we found that standing dead Fraser fir over 5 inches (12 cm) in diameter at breast height (d.b.h.) ranged from 44% on Roan Mountain to 91% in the Great Smoky Mountains National Park. Spruce mortality was not alarming, with a range of 3% on Roan Mountain to a high of 14% on Mount Mitchell. Patterns of tree death are closely associated with species composition within the stand and are determined by elevation. These patterns are consistent with accounts of balsam woolly adelgid infestation.

A total of 16 different data themes such as topography, transportation, ownership, hydrology, balsam woolly adelgid history, and disturbance history were entered into the GIS for analysis in relation to the spruce-fir type.

INTRODUCTION

In recent years, the spruce-fir forests of the southern Appalachian mountains have shown tree decline and large areas of concentrated timber mortality (figure 1). Quantitative evidence of red

Figure 1.–Area of severe spruce-fir mortality in the southern Appalachian Mountains.

spruce (*Picea rubens* Sarg.) decline has been reported in the high-elevation forests in New England (Siccama and others 1982; Johnson and Siccama 1983; and Scott and others 1985). Extensive surveys to document the status of mortality and decline of spruce-fir forests have been conducted in portions of New Hampshire, New York, and Vermont (Weiss and others 1985) and in West Virginia (Mielke and others 1986). Tree ring analysis showing a decline in the annual radial increment of red spruce indicated marked decline in growth since the early 1960's (Adams and others 1985; Hornback and Smith 1985; McLaughlin and others 1986).

At lower elevations in the southeast, atmospheric deposition was mentioned as a possible cause of pine growth loss (Sheffield and Cost 1987; Smith 1985). Strong emphasis was placed, however, on the fact that effects of deposition-related stresses are difficult to separate from the effects of other factors. Concern about mortality in the spruce-fir forests of the southern Appalachian mountains
indicated an immediate need to conduct a survey to map the extent and severity of the damage.

This survey project was conducted by the USDA Forest Service, Southern Region, Forest Pest Management (FPM). It was funded through the National Acid Precipitation Assessment Program (NAPAP) for the Spruce-fir Research Cooperative and National Vegetation Survey, as well as the Southern Appalachian Research/Resource Management Cooperative (SARRMC).

Under NAPAP, a national effort called the Forest Response Program was established to provide information on how forests respond to airborne chemicals. Our project examines the Program's Policy Question No. 1: Is there a significant problem of forest damage in North America that could be caused by acidic deposition alone or in combination with other pollutants? This survey project was designed to provide information on two scientific questions identified by the Spruce-Fir Cooperative about Policy Question No. 1: (1) Are changes in growth and mortality and the presence of unusual foliar symptoms in red spruce-fir forest greater than can be attributed to typical trends and levels of natural variability? and (2) What spatial patterns, if any, exist ingrowth and mortality and in the presence of unusual symptoms in red spruce-fir forests and how do these patterns relate to spatial patterns of pollutant exposure?

Because of concern about the declining red spruce and Fraser fir (*Abies fraseri* [Pursh] Poir) resource, the FPM staff evaluated this forest type in the southern Appalachian mountains, beginning in 1984, to determine the extent of tree mortality over the range of the spruce-fir type in the southern Appalachian Mountains. Under authority of the Cooperative Forestry Assistance Act of 1978, the USDA Forest Service is responsible for assessing the effects of damage from insects and

diseases and from abiotic agents on the nation's forest resources. This responsibility is carried out directly on Federal lands and in cooperation with state foresters on State and private lands.

In addition to the administration of the National Forest System, the USDA Forest Service is responsible for the Forest Service Research Program and the cooperative State and Private Forestry Program. The latter program was authorized by the Coop.For. Assist. Act of 1978 to "detect, evaluate, prevent, retard, suppress, or eradicate incipient, potential or emergency outbreaks of destructive insects or diseases on or threatening all forest lands regardless of ownership." Damage caused by air pollution has been recognized as a disease.

The FPM staff conducts surveys to detect insect and disease outbreaks and evaluates pest prevention and suppression programs. The FPM staff also makes pilot tests of new materials and methods of suppression. Related activities include transfer of information and technology from research, as well as implementing integrated pest management strategies. The FPM staff has been involved with surveys and biological evaluations in the spruce-fir forests of the southeast since the balsam woolly adelgid (*Adelges piceae* [Ratzeburg]) was first discovered in the southern Appalachians in 1956.

The Spruce-fir Ecotype in the Southern Appalachian Mountains

The spruce-fir type represents an extremely valuable resource in the South because of its unique natural beauty and its importance for recreation. It is also considered by many to be a threatened forest type because of its marked decline in area. In the Southeast, spruce-fir stands are of limited commercial timber value, although Fraser fir is a highly prized Christmas tree. These stands occur in such notable landmarks as Mount Mitchell (Black Mountains) State Park, site of the highest mountain in the Eastern United States; the Great Smoky Mountains National Park; the Balsam Mountains; and the Mount Rogers National Recreation Area.

This forest type occupies the highest peaks in the states of North Carolina, Tennessee, and Virginia (figure 2). The Appalachian Trail crosses through much of the spruce-fir type. All of these areas are of major scenic and recreational importance.

Figure 2.–Spruce-fir forests occupy the highest peaks in North Carolina, Tennessee, and Virginia.

Ecologically, these forests are quite similar to the boreal forests of the northern U.S. and Canada. The major differences are in the greater diversity of associated plant species in the southern forests. Fraser fir is the fir component in the South while balsam fir (*A. balsamea* [L.] Mill.) is the fir component in the North (Oosting 1951). Red spruce is the spruce component in both areas.

In this booklet, the term "spruce-fir forests" will be used to describe forests of varying proportions of red spruce and Fraser fir, with varying amounts of other hardwoods and conifers within the stand component. The spruce-fir type occurs between 4,400 feet (1,341 m) in the Great Smoky Mountains National Park to 6,684 feet (2,037 m) on Mount Mitchell. A mixture of spruce and fir may occur at any elevation, but generally red spruce predominates at the low elevations and fir predominates near the summits of the peaks. A relatively pure zone of spruce and fir begins at 5,300-5,500 feet (1,615-1,676 m) (Ramseur 1960; Schofield 1960; and Whittaker 1956). Red spruce grows larger and lives longer than Fraser fir, but the latter grows more rapidly and produces more prolific seed crops.

Because of the geography and topography of the region, spruce-fir forests in the South occur as a series of island-like stands at high elevations.

There is a sizable gap in the distribution of spruce-fir in eastern North America between latitude 38° to 40° north because the mountains do not reach high enough elevations within this region (White 1984). Southern stands are therefore isolated from the northern spruce-fir forests. The total available habitat for spruce and fir in the southeast is a relatively small area. Only seven mountainous areas have spruce-fir forests and an eighth has spruce forests only (Ramsear 1960). Red spruce predominates in high elevations on exposed and poor sites, not because these areas are best suited for its growth, but because these sites are less favorable for its competitors (Hart 1959).

The climate in the spruce-fir areas is severe in the winter, where snow may remain most of the winter and winds may exceed 100 mph (161 kmph). Rainfall is generally abundant and distributed throughout the year, but the area has experienced dry periods. The soils are highly organic, but in many spots shallow (as indicated by many areas of windthrow in severe windstorms).

Current Threats to the Spruce-fir Ecosystem in the Southern Appalachian Mountains

Discovery of the balsam woolly adelgid, an insect introduced from Europe, in the southern Appalachians provided a wealth of information concerning mortality of spruce and fir. The southern Appalachian spruce-fir forests are undergoing rapid change. The most dramatic change is the high mortality of mature Fraser fir caused by the balsam woolly adelgid. Recent attention has shifted, however, to the role of atmospheric deposition in damaging the high elevation forest.

Atmospheric Deposition

Theoretically, the high elevation forests in the mountainous areas receive substantially more atmospheric deposition than the surrounding forests of the lowlands. Wet deposition should increase with elevation because of increased cloud cover, precipitation, and increased deposition of snow, which may be more polluted than rain. Cloud water deposition is likely to be significant at high elevations because of the frequent immersion of mountain peaks and presence of wind-driven clouds. Dry deposition should be greater in high-elevation forests because of greater wind speeds, higher relative humidities, greater surface area of vegetation present during the entire year, and greater filtering efficiency of needles compared with broad leaves (Lovett 1984). Bruck (1984 and 1985) has suggested that atmospheric deposition is the potential cause of spruce-fir decline in the southern Appalachian mountains.

Scientific evidence, however, can neither confirm nor refute whether atmospheric deposition has caused the reduction in spruce-fir tree and stand growth in the Southeast. Effects of deposition stresses on forests are difficult to separate from effects of other factors (Smith 1985). The complicated nature of forest decline has made it extremely difficult to develop a cause and effect relationship. Even if air pollutants were not involved, the loss of mature Fraser fir, one of two major dominant tree species, will bring widespread change to this ecosystem (DeSelm and Bonner 1984).

Abiotic Factors

Spruce-fir forests are predominantly in regions of high rainfall. During periods of drought, water deficits might become apparent here before they occur in other areas where soil water reserves are more abundant. Drought is frequently reported as a major cause of tree mortality. Winter drying or desiccation occurs when the tree crown becomes active from warming winds or solar radiation while lower parts (below the snow) remain frozen, and foliage burn or browning occurs (Sakai 1970).

Rime ice is frequent at high elevations. Such icing, accompanied by high winds, is extremely damaging to trees (Griggs 1946).

In addition, spruce, which is typically shallow rooted, is easily windthrown. Large areas of Fraser fir mortality make adjacent stands also susceptible to windthrow. At high elevations tree crowns are shaped by the prevailing winds. The

constant swaying of the tree in the wind may sever the connection of the rootlets, breaking and tearing them. As a result, the tree gradually dries out and seems to die for no apparent reason (Chittenden 1905).

Biotic Factors

A distinct lack of biotic interactions involved in spruce-fir decline in the southern Appalachian mountains was reported by Bruck (1987). Bruck's survey failed to detect significant populations of harmful insects, and gross pathology indicated other natural or anthropogenic influences.

Results of a recent survey conducted by TVA (Groton 1985) found the major source of mortality for fir was the balsam woolly adelgid. Suppression from overcrowded stands was the next most common cause of death. Spruce mortality was found to be generally much lower than fir. Mortality of spruce was primarily from weather and suppression.

In West Virginia, surveys found the primary symptom associated with declining red spruce was branch mortality associated with *Valsa kunzei* Fr. (pycnidial stage = *Cytospora kunzei*, Sacc.) (Mielke and others 1986). This was suggested as contributing to the reported growth decline in West Virginia (Adams and others 1985). This fungus has not been found to cause conspicuous mortality or decline in the southern Appalachians.

The four-eyed spruce bark beetle, *Polygraphus rufipennis* (Kirby), and the southern pine beetle, *Dendroctonus frontalis* (Zimmerman). are occasional pests of red spruce in the South. Annosum root rot, caused by the fungus *Heterobasidion annosum* (formerly called *Fomes annosus*), is known to affect Fraser fir. Insects such as spruce budworm, *Chloristoncura fumiferana* (Clemens), and spruce beetle, *Dendroctonus rufioennis* (Kirby), although major pests farther north, do not occur in the southern Appalachian mountains. The eastern dwarf mistletoe caused by the parasitic plant *Arecuthobium pusillum*, which is a major disease of red spruce in the North, does not occur in southern spruce-fir forests.

Balsam Woolly Adelgid

Infestations of the balsam woolly adelgid were first discovered in the southern Appalachian mountains in 1956, when it was reported from the Shenandoah National Park in northern Virginia (McCambridge and Kowal 1957). The following year, extensive fir mortality in the vicinity of Mount Mitchell was attributed to this insect (Speers 1958). In 1962, balsam woolly adelgid was detected within a Christmas tree production area on Roan Mountain (Ciesla and Buchannan 1962). In 1963, detection surveys revealed the presence of this insect on Grandfather Mountain in North Carolina (Lambert and Franklin 1963), and in the Great Smoky Mountains National Park in the vicinity of Mount Sterling in North Carolina (Ciesla and others 1963).

As early as 1963, aerial and ground surveys were developed to detect localized infestations of the balsam woolly adelgid (Ciesla and others 1963 and 1965, Lambert and Ciesla 1966). As of 1966, all areas of spruce-fir type in the southern Appalachians were known to have at least localized infestations except the Balsam Mountains, North Carolina, and the Mount Rogers area of Virginia (Talerico 1965). As of 1968, balsam woolly adelgid was found over 16% of the total host type in the three-state area. The adelgid was detected in a remote area of the Balsam Mountains for the first time in 1968 (Raushenberger and Lambert 1969) and on Mount Rogers in southwest Virginia in 1979 (Lambert and others 1980). Subsequent stem analysis indicated the balsam woolly adelgid had been present on Mount Rogers since about 1962.

A weakness in the aerial detection survey was that infestations were not detected until some fir mortality had occurred. By then, aphid infestations were well established and usually quite extensive. This situation made control measures, particlarly in inaccessible areas, impractical. A network of traps was established in an attempt to detect wind-borne eggs and first-instar nymphs, the two stages in the life cycle of the insect subject to dispersal. These traps detected infestations before they were visible from aerial surveys (Lambert and Franklin 1963; Lambert and Ciesla 1967).

Evaluation of balsam woolly adelgid during 1969 emphasized the establishment of protection boundaries around accessible high-value stands of fir (Rauschenberger and Lambert 1970). The 1969 survey and evaluation techniques were modified from previous years to take into account the accessibility of given areas where applied control, if needed, could be carried out. Preventative spraying for control of the balsam woolly adelgid on high-value areas was discontinued. During the 1970's emphasis shifted to the protection zones (Johnson 1980).

Lindane had been used to protect critical high-use recreation areas on Mount Mitchell during the 1960's (Ciesla and others 1963) and on Roan Mountain beginning in 1971 (Ward and others 1973; Johnson and others 1980). A 200-foot (61 m) wide zone on both sides of primary access roads were sprayed with lindane. Subsequently, a less toxic and less persistent substance comprised primarily of a fatty acid was developed and applied against the balsam woolly adelgid (Puritch 1973). Pesticides have limited use against the adelgid because the method of application requires that they must be applied from within the stand to each stem. Aerial application techniques have not been developed.

The balsam woolly adelgid passes through two and occasionally three generations per year in North Carolina (Amman 1962). Within 10 to 12 days of being deposited, eggs hatch into first-instar nymphs (crawlers) which are mobile (fig.3). This stage, which lasts approximately 8 days, is the only period in the adelgid's entire life cycle that it is able to move about. Upon finding a suitable spot on the fir, the adelgid inserts its mouth parts into the tree. Once this is accomplished, that particular adelgid never moves again.

Balsam woolly adelgid in North America is free of damaging parasites and diseases. Introduction of foreign and native insect predators had little effect on population dynamics in the southern Appalachians (Amman 1961, 1970; and Amman and Speers 1971).

High ambient air temperatures are not fatal to the balsam woolly adelgid. Consistently warmer

Figure 3.–Balsam woolly adeglid (nymph) crawlers infesting the bole of Fraser fir.

than normal temperatures would benefit the population (Balch 1952). Amman and Talerico (1967) reported that temperatures down to -34° F caused higher than normal mortality, but no significant control resulted from these rare, low temperatures. Balsam woolly adelgid, however, is subject to considerable amount of control by low winter temperatures in the northern portions of its New England range (USDA Forest Service 1985).

Injury by the balsam woolly adelgid occurs when a substance contained in the insect's saliva is injected into the plant tissue. The substance stimulates cell division in the cambium layers and results in the production of a dark, hard, brittle wood commonly referred to as "redwood" or the German "rotholtz" (Balch 1952). This plant tissue is very similar to premature heartwood, which results in greatly reduced translocation of water and minerals to the crown. This causes water stress and death of the tree (Puritch 1973). The tree crown then changes color. The adelgid population collapses prior to the completion of change in foliage color (Amman and Talerco 1967).

The inability of Fraser fir to seal off the feeding site and contain the adelgid secretions results in damage to the plant tissue. Damage may take one of two forms: gouting or gout disease as the result of infestation on twigs and as characterized by swelling or distortion of twigs and smaller branches. Stem infestations result in death of the cambium layer and are the predominant form of attack on Fraser fir. This fir species is highly susceptible to

adelgid infestations, and infested trees ultimately die from stress related to the attack. This occurs from 1 to 7 years after initial infestation.

Johnson (1977) found that the largest Fraser fir in a stand supported the highest adelgid population. From fir crowns, the adelgids spread upslope, borne by wind. Small Fraser fir saplings and seedlings do not build up large populations of balsam woolly adelgid. Large trees with their crowns exposed to air currents are the first to become infested, and for several years prior to death, support large adelgid populations. Insect populations on trees growing under average or high stand-densities occur mainly at the base of and just within the crown (Eagar 1984). Therefore, it is often difficult to detect the presence of balsam woolly adelgids by observations made at eye level, particularly at stages of early infestation and development.

The balsam woolly adelgid has left its scars in the spruce-fir forest. Eagar (1984) states that the initial wave of the balsam woolly adelgid in the southern Appalachians is nearly completed. Previously protected areas, where treatment has been abandoned, are now heavily infested and have sustained significant mortality. Such mortality is especially notable on Mount Mitchell and Roan Mountain.

OBJECTIVES

The primary objectives of this project were:

1. Locate and map natural stands of all red spruce and Fraser fir in the southern Appalachians.

2. Acquire complete aerial photographic coverage to interpret and classify all red spruce and Fraser fir mortality (percentage of dead standing trees) in Tennessee, North Carolina, and Virginia.

3. Using a combination of aerial photographic sampling and ground inventory, estimate losses within the spruce-fir type.

4. Acquire large scale aerial photography of previously established research plots.

5. Develop and implement a geographic database on the extent and intensity of mortality in the spruce-fir type in North Carolina, Tennessee, and Virginia.

6. Provide for comparisons between the extent and intensity of mortality in relation to other geographic information through the computer analysis, storage, and display of spatial (geographic) information.

Secondary objectives were:

1. Provide baseline data on the extent of mortality to be used to determine trends by comparing present spatial distribution of spruce-fir conditions with spatial distribution obtained from future inventories.

2. Determine the proportion of spruce-fir and other species stocking within the spruce-fir type, for analysis in relation to other geographic information.

Determining the causes of mortality was not an objective of the survey, although historical records of mortality and major mortality factors were reviewed.

METHODS

Aerial Photo Acquisition and Annotation

Maps displaying all known locations of spruce-fir type in the southern Appalachians were obtained and reviewed from historical records of balsam woolly adelgid compiled by FPM. Researchers known to be conducting work in spruce-fir were contacted to help delineate known natural stands. All maps showing previously known boundaries of spruce-fir were assimilated and transferred to aeronautical sectional charts. Flight lines were plotted on existing spruce-fir type maps, as well as aeronautical charts for flight planning. The beginning and end of each flight line were digitized to obtain latitude and longitude coordinates to program a Loran-C navigation system. Loran-C guidance allowed for extended flight line navigation and control of side lap between parallel flight tracks. Loran-C navigation greatly increases the efficacy of aerial survey and photographic operations (Dull and Clerke 1983). This is important in the southern Appalachian mountains where weather and visibility severely limit available flight days.

Flight lines were spaced at 1.1:19 statute mile (1.9 km) gain per line for 30% side lap. Exposure intervals were controlled by a viewfinder with a traveling grid which coincided with the groundspeed of the aircraft. This was critical over terrain with rapid elevational changes to provide 60% end lap. Exposure intervals at 150 mph (241 kmph) were every 16 seconds. A single negative covered 1,860 acres (753 ha) with an area gain (stereo coverage) of 659 acres (267 ha) per exposure and a gain per exposure of 0.68 miles (1 km) along flight lines.

Color infrared (CIR; Kodak film type 2443) aerial photography at a scale 1:12,000 [1 inch (2.54 cm) = 1,000 feet (305 m)] of the entire spruce-fir type was acquired in stereo during the summer (leaf-on season) of 1984. Coverage was also obtained for the area well beyond the spruce-fir type. A USFS Aero Commander 680-F equipped with a Wild RC-10, 9x9 inch (23x23 cm) format, camera with a 6-inch (15 cm) focal length lens was used to acquire the photography. In the winter of 1985, true-color positive transparencies (Kodak film type 2448) were acquired in stereo during the leaf-off season over the entire spruce-fir range, also at a scale of 1:12,000. This photography was designed to modify the previously identified boundaries and mortality strata for more specific and detailed evaluations. Underflights were made of previously established research plots at a scale of 1:4,000 [1 inch (2.54 cm) = 333 feet (102 m)]. All photography was indexed on USGS 1:24,000 scale topographic sheets. The photography and photo indexes were made available and used by numerous investigators conducting spruce-fir research.

A scale of 1:12,000 was used since it allowed resolution of individual trees under magnification. This scale also gave expanded coverage of each frame to identify check points and to provide ground reference for control. A nominal photo scale of 1:12,000 required flying at an altitude of 6,000 feet (1,829 m) above average ground elevation.

Photo Interpretation

Complete stereo coverage of the color infrared positive transparencies were provided to the photo interpreters. All aerial photographic interpretation was conducted at the photo interpretation facilities of the USDA Forest Service, Aerial Survey Team, Doraville Field Office, GA. (This facility has since been moved to the Atlanta Regional Office.) The effective area of each photo frame and the photo scale were determined. After annotation, the photo interpreters stratified the area within each geographic region by mortality class and determined the outer boundaries where the

spruce-fir type occurred. Using Bausch and Lomb 240 Zoom stereoscopes mounted on MIM-4 Richards light tables, skilled aerial photographers delineated spruce-fir boundaries directly on the transparencies.

For this project, the spruce-fir type was defined as all areas containing dominant and codominant spruce and fir visible on the aerial photography. Varying proportions of hardwood and other conifers were found within this type, especially at lower elevations. Photo interpreters did not distinguish between spruce and fir. The boundaries of the type and mortality classes were transferred to 1:24,000 scale USGS topo maps. Within the spruce-fir type, the following categories of mortality were recognized: (1) light (less than 30% of the standing dominant and codominant trees dead); (2) moderate-to-heavy (30% to 70% standing dominant and codominant trees dead); and (3) severe (greater than 70% of the standing dominant and codominant trees dead). Maps were prepared for data entry into the Geographic Information System.

Sampling Methods

Stratification and Selection of Aerial SamplePlots

During the photo interpretation, individual areas were sampled within the three mortality classes as described in the photo interpretation methods. Each mortality class was randomly sampled in proportion to the area of spruce-fir type affected. A total of 232 sample plots, 0.2 acre (.0809 ha) in size, were selected in the Black Mountains, Roan Mountain, Balsam Mountains and Great Smoky Mountains National Park (table 1). Sample plots were not established on Mt. Rogers because no large, continuous areas of mortality were observed at the time of the survey. Randomly selected 0.2 acre (.0809 ha) plots were viewed in stereo to determine the number of dead spruce and fir trees and the total number spruce and fir trees visible in the plots. In addition, the elevation of each sample plot, mortality classification, and the plot number were all carefully recorded. Using a zoom transfer scope, we then transferred the location of the plot to 7-1/2 minute topographic maps.

Table 1.—Number of aerial photo sample plots, by geographic region

Geographic region	Number of aerial photo sample plots
Balsam Mountains	50
Great Smoky Mountain National Park	82
Black Mountains	68
Roan Mountain	32
Total	232

Stratification and Selection of Ground Sample Plots

A random sample of ground plots was obtained stratified, by elevation. The three elevation strata were: (1) less than 5,200 feet (1585 m); (2) 5,200 feet - 6,000 feet (1,585 - 1,829 m); and (3) higher than 6,000 feet (1,829 m). The stratification was based on the photo interpretation of the entire spruce-fir forest type for each of the six geographic areas.

The allocation of ground plots within each stratum was done using probability proportional to size (PPS) sampling in accordance with acres of spruce-fir type within a given geographic area. Areas sampled more intensively were done so because of varying acreage of spruce-fir type; that is, the larger areas contained more sample plots.

With the exception of a few plots on the Great Smoky Mountains National Park, each sampled ground plot corresponds to an aerial plot. This overlapping of aerial to ground plots allows considerable flexibility in the statistical analysis. For example, using this double sampling approach, correlation and regression analyses were done for mortality as estimated in each manner, aerial and ground.

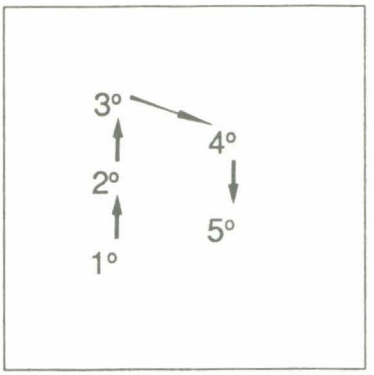
A total of 123 ground sample plots were subsampled from the aerial photo plots (table 2). Using the aerial photos in the field, ground crews located the center of the photo plots on the ground and marked them with a metal stake.

Starting at the center of the plot, a cluster of five sampling points were established with the center stake serving as the first point and the other four systematically arranged in a procedure similar to that used by the USDA Forest Service, Southeastern Forest Experiment Station, Forest Inventory and Analysis (FIA) Work Unit. The primary difference was that only five points were sampled as opposed to ten points.

Ground sample plots were established as follows:

Azimuth and	Horizontal Distance	Point	to	Point
0°	70 ft (21 m)	1		2
0°	70 ft (21 m)	2		3
120°	70 ft (21 m)	3		4
180°	70 ft (21 m)	4		5

A typical sample plot can be depicted as follows:



Data were taken at each point in a variable size plot. Each point was established by a prism with a basal area factor of 37.5. A fixed radius plot of 6.8 ft (2 m) was also established at each point in the cluster. There were two sets of data taken at each point in the cluster on two separate data sheets. The following data were taken on each tree for the variable size sampling points: (1) species; (2) d.b.h. [trees > 5 inches (13 cm)]; (3) crown condition; (4) total height; and (5) crown position. On the 6.8 ft (2 m) radius plots the following data was taken on each tree: (1) species; (2) d.b.h. [trees > 1 inch (2.54 cm)]; (3) crown condition; and (4) crown position. General information such as slope, aspect, and presence of gouting or balsam woolly adelgid were collected for each plot.

Table 2.—Number of ground sample plots by geographic region

Geographic region	Number of ground sample plots
Roan Mountain	30
Black Mountains	33
Balsam Mountains	30
Great Smoky Mountains National Park	30
Total	123

Implementation of the Geographic Database

Geographic Information System (GIS) technology was used in the construction of the spruce-fir database in the southern Appalachians. Three major software systems comprise the GIS used for the data capture, analysis, and display: (1) the Analytical Mapping System (AMS); (2) the Map

Overlay and Statistical System (MOSS), including a raster processing system (MAPS); and (3) the Cartographic Output System (COS).

MOSS was selected to implement the spruce-fir data base because it is a public domain, government supported system and would not require users to purchase a software license. Also, MOSS is a primary GIS used by the Bureau of Land Management, U.S. Fish and Wildlife Service, Bureau of Indian Affairs, U.S. Army, the U.S. Geological Survey, many State and local governments, universities, and private companies. There is already a large body of expertise on the MOSS system within the Federal government because these agencies are committed to maintaining the software. Plans are being made to invest for improvements in MOSS. MOSS operates on Data General, Prime and VAX minicomputers.

There are some drawbacks to the system. It is basically a 10-year-old technology that has been enhanced and upgraded. It does not have a relational database manager. Multiple attribute files, however, developed by relational database managers, can be linked to the spatial data. It processes data in polygon form, which is slow, rather than in arc-node form, which is much faster and less redundant.

Map Digitizing and Data Entry

Before data entry, maps were reviewed to verify attribute placement and polygon closure, as well as edge mapping adjacent map sheets. The boundaries of the spruce-fir type, with the interior areas classified by mortality, along with the other data themes, were digitized from USGS, 7.5 minute quadrangle sheets.

AMS was used for all data capture related to this evaluation. AMS is a digitizing, editing, and data base management system used to get ground information for any size area from aerial photographs or map sheets and store it in a digital data base. The AMS table digitizing subsystem allows the user to enter information found on base maps and data overlays from base maps into the system. We entered with a digitizing tablet and cursor. The digitizer traces the data with the cursor while pressing a specified button on the cursor. This sends the information to the computer where it was mathematically translated into a coordinate pair of positive or negative integers based on the map's center coordinate. Digitizing was done in arc-node format with attributes assigned to the left, center, and right sides of each arc. All mapped data in AMS was in a common ground-based geographic reference system.

A rigorous on-line verification and editing capability was used to correct errors as they were encountered. This ensures topological validity by requiring that error corrections and edge ties between maps be completed before the file can be moved to the database. When the digitizing was completed, the map was put through a rigorous verification procedure that included both visual and computer verification of the data.

All information entered into the system was organized on the basis of individual maps. Collectively, maps were organized into projects which have one or more data themes. Projects usually included a number of maps registered at a common scale over a common area. For the spruce-fir data base, USGS 1:24,000 scale topo maps (quads) were used as the base series maps.

Within this project there were a number of data themes. They represent the spatial data stored in the data base and list legal attributes for specific data type. All maps completed in the digitizing process were stored under the theme name in the project. The following is a list of the data themes for the spruce-fir database in the southern Appalachians:

1) Spruce-fir type boundaries

2) Spruce-fir mortality stratification

3) Topography

4) Transportation

5) Ownership

6) Hydrology

7) Study plot locations

8) Photo index

9) Disturbance history

10) Balsam woolly adelgid protection boundaries

11) Balsam woolly adelgid mortality history

12) Balds

13) Spruce-fir forest type (with hard wood component)

14) Railroad right-of-ways

15) 1960 mortality for Mount Mitchell

16) Administrative boundaries

GIS Data Analysis and Map Production

MOSS is a geographic analysis system. AMS data base files were placed in the MOSS database and projected in one of 20 available map projections. MOSS was designed to allow users to retrieve, analyze, and display maps and other spatial data.

GIS performs sophisticated manipulation and analysis functions. The most frequently used and primary advantage of a GIS versus other cartographic systems is map overlay. The most difficult and most useful of these functions, the polygon on polygon overlay, was designed to calculate automatically new polygons based on the mathematical overlay of polygons from separate maps. This was performed by geometrically determining the line intersections of overlapping polygon boundaries. Attributes from the separate polygon maps were combined automatically and associated with the resulting map file to determine which map elements coexist at particular locations.

A wide variety of other analytical functions were available in MOSS to analyze geographic information for a variety of purposes. Examples (by no means an inclusive list) of several different procedures used are: (1) topological overlays in which geographic elements from two or more separate files were joined or related to one another to create an integrated cartographic file; (2) polygonization in which linked segments were chained together to form a polygonal boundary; and (3) relational matching in which two attributes are related to one another to form the desired functional purpose.

MOSS is capable of producing hard copy map outputs. For more detailed cartographic outputs, however, the COS subsystem was used. COS was used to produce high-quality graphic and geographic outputs in the form of color, thematic maps, diagrams, index maps and graphs.

To address the primary objectives of the project, many GIS analyses of the geographic data were conducted and integrated with the data collected during the aerial and ground surveys. Obviously, not all relationships could be analyzed, considering the great number of functional combinations, overlays, models, or interpretations that could be derived from the data. Reviewed by geographic region and in total for the southern Appalachians, major emphasis was placed upon the following analysis and production of maps to show their spatial relationships:

1. Location and area of spruce-fir type.

2. Distribution of mortality within the spruce-fir type.

3. Spruce-fir mortality classification expressed in number of acres and percent of area.

4. Acres of mortality stratified by elevation and expressed as a percent of total area.

5. Percent of spruce and fir mortality stratified by elevation.

6. Percent of stand component comprised of spruce-fir, stratified by elevation.

7. Review of present mortality with past mapped mortality where available.

8. Review of current spruce-fir mortality with maps of disturbance histories and land use.

9. Review of present mortality with balsam woolly adelgid history.

10. Major spruce-fir ownership distributions.

11. Spruce-fir mortality by ownership, review ing distribution and acreage.

12. Volume of spruce versus fir by condition class.

13. Relationship of spruce versus fir volume and condition by elevation.

14. Distribution of study plot locations within the spruce-fir type.

Computer System Configuration

FPM in Atlanta operates a system dedicated to GIS and digital image processing with the following hardware:

CPU
- DG MV15000 with 8 megabytes of memory and floating point processor

DISK DRIVES
- 592 Megabytes fixed drive
- 5 Megabytes fixed, 5 megabytes removable
- 192 Megabytes removable (2)

TAPE DRIVE
- High Density 1600/6250 bpi

OUTPUT DEVICES
- 36-inch color electrostatic plotter
- 36-inch, 8-pen plotter
- Video graphic camera
- System printer
- Ink Jet plotter

USER STATIONS
- Two large tablet digitizers (44x66 inches (112x168 cm), backlighted) each with text and graphic terminals
- Image processer and display
- Three high resolution color graphic terminals
- Three text terminals

Quality Assurance

The MOSS GIS software has many built-in assurances concerning data quality and integrity. A few examples are:

1. Maps being digitized cannot be stored in the permanent database until they have undergone an automated topological verification procedure.

2. Maps being digitized can be reprojected to any of twenty projections to obtain hard-copy plots and overlay on supporting material.

3. Map data can be reprojected into any of the twenty projections to enhance calculation concerning area, length, and perimeter.

4. Data completeness checks were performed, identifying and resolving invalid or ill-defined features.

5. Maps that were undergoing significant data change when a hardware operating system or program failure was encountered may be flagged as useless. Recovery techniques are provided for these specific events (Alberts and others 1987)

In using maps in the traditional way, the method has been to look at the maps in order to interpret them. Geographic relationships and meanings have generally been derived through the process of human analysis. Through the use of a GIS, there was a significant reduction in the need for this human analysis. As a result, a wide variety of the interpretations of the data with a minimum of human intervention (and corresponding data corruption) was achieved through the use of fully automated procedures. In addition, there were many advantages to using automated GIS technologies, such as maintaining data in a physically compact format and retrieving them at a much greater speed and lower cost. There was also the opportunity to integrate data collections, spatial analysis, and a decision-making process all into one common information base.

All automated techniques involved a substantial amount of processing or editing subsequent to the initial data capture. These include (1) plotting or printing of digitized coded data for visual editing; (2) topological checking to ensure correctness within data sets; (3) removal of concurrent lines captured to represent the same map vector; (4) polygonization of arc information into polygons; (5) editing XY coordinate data; and (6) edge map analysis.

RESULTS AND DISCUSSION

Aerial Photography Acquisition, and Annotation

Color and color infrared aerial photographic coverage of the entire spruce-fir type in the southern Appalachians was obtained. Portions of the spruce-fir type had been photographed in stereo or sampled at various scales over the past 25 years, but complete coverage over a short time span was lacking.

The 1:12,000 scale was acceptable for mortality stratification; however, a smaller scale would have reduced cost and facilitated the type mapping and base map transfer process. In general, control for transfer of the photo interpreted information in remote areas was limited, but adequate.

Weather was a major factor limiting available flight time. Close coordination and timing between the photographic crew, a contract meteorologist, and Federal Aviation Administration, Flight Service Station, was maintained.

A total of 48 flight lines was required to adequately cover the area. Flight line orientation was east to west to reduce the required number of lines. The principal point of each frame, along with the exposure number, was plotted on USGS topo maps. Twenty-seven maps were required to index the CIR coverage flown for this project.

In general, the color balance was good, but a combination of emulsion, exposure, and processing produced a slightly hot, (too red) image. Color IR film was chosen to penetrate haze, separate conifers and hardwoods, and enhance separation of conifer mortality and foliage loss. The true color transparencies obtained during the leaf-off period helped further to delineate the boundaries of the spruce-fir type. Procedures followed during aerial photographic acquisition were compatible with standard requirements for aerial photographic mapping missions (Thompson 1966, U.S. Department of Agriculture 1979).

Aerial Photographic Interpretation

Color infrared (CIR) aerial photography has been used in inventories to identify vegetation communities with a spruce-fir component and as an intermediate sampling stage for estimating levels of tree mortality (Aldrich and Drooz1967, Weiss 1985, Ciesla and others 1986b; Mielke and others 1986). As early as 1957, Pope reported that photo interpreters could accurately count fir trees damaged by balsam woolly adelgid on color or CIR aerial photography in the Pacific Northwest.

Past surveys using conventional ground techniques alone were impractical because of the rugged terrain, remote location, and the high cost of an adequate sample. For estimating mortality, a double sampling method using both ground and photo plots with sequential color photography is considered several times more efficient than ground surveys alone. Inventories of forest damage using aerial photography to estimate number of trees killed and associated volume loss from outbreaks of forest damaging agents across the United States has been well documented (Wear and others 1964, Ciesla and others 1971, Klein 1979, Stewart 1982, Ward and others 1985, Weiss and others 1985; many others). A number of approaches have been designed to inventory forest decline using CIR aerial photography in Europe (Ciesla and Hildenbrandt 1986). In West Germany, Ciesla reports that symptoms of forest decline are actually more visible on large-scale CIR photos than they are on the ground because symptoms are concentrated in the upper crown.

Other advantages for the use of aerial photography are that aerial photos provide a permanent record of the forest condition at a point in time and provide an opportunity to assess change in forest conditions with sequential coverage.

Disadvantages and operational problems involved in use of aerial photography include (1) unfavorable weather during acquisition periods, (2) coordinating ground survey data acquisition with aerial photo interpretation, (3) correlation of ground truth data with photo interpreted data for statistical analysis, and (4) inconsistent color balance of CIR film.

Photo interpretation is a time consuming, often tedious task. Photo interpreter fatigue is a problem in maintaining consistent data quality. Photo interpretation also tends to be subjective, and data quality is strongly influenced by the individual training and experience of photo interpreters and film quality. Three full-time photo interpreters/aerial photographers, each with 20 or more years of experience, were used in this evaluation.

The delineation of the spruce-fir forest type in the southern Appalachian mountains was mapped on topo maps. The spruce-fir type was defined, for this evaluation, to be areas containing spruce or fir, or both, visible on the aerial photograph. This definition of type is an important factor in the estimates of total spruce-fir area and its relation to other geographic features.

The ecotone between spruce-fir and hardwood forest types is relatively abrupt. Investigations of this boundary have shown that the rate of vegetation change with elevation is greater across the boundary than on either side of it (White 1984). The continuous nature of the vegetation change means that the exact placement of the elevational ecotone is subjective. Therefore, previous estimates of spruce-fir area may differ substantially, depending upon the definition of the spruce-fir type components, that is, spruce-birch, spruce-hemlock, or other vegetation types.

The abrupt ecotone boundary was readily identified on small-scale aerial photography (scale of 1:12,000 to 1:24,000) as interpreted from the 1984-85 coverage and smaller scales acquired by FPM in the past. The 1:12,000 scale was considered a compromise to conduct both tree level and larger stand/ecotone level studies. For control of boundary placement, smaller scales are preferred to reduce costs related to photo acquisition and time required for interpretation and data transfer to base maps. The trend in scale determination is toward the smaller scale, especially if zoom-stereo scopes and high-resolution transparencies mounted on light tables can be used. Aerial photos of a larger scale (1:8,000 and larger) would be required if more subtle tree symptoms such as discolored foliage and top dieback were to be interpreted.

The determination of the mortality stratum required close attention to subtle changes in color and texture of the vegetation. Standing dead trees exhibited a gray appearance. Spruce-fir type, in general, appeared in hues of red-brown, red-violet or dark red, in contrast to the pink or bright-red of hardwoods (figure 4). Close scrutiny of the film was required to avoid including pine species, hemlock, and hardwood stands that did not contain spruce-fir in the type boundary.

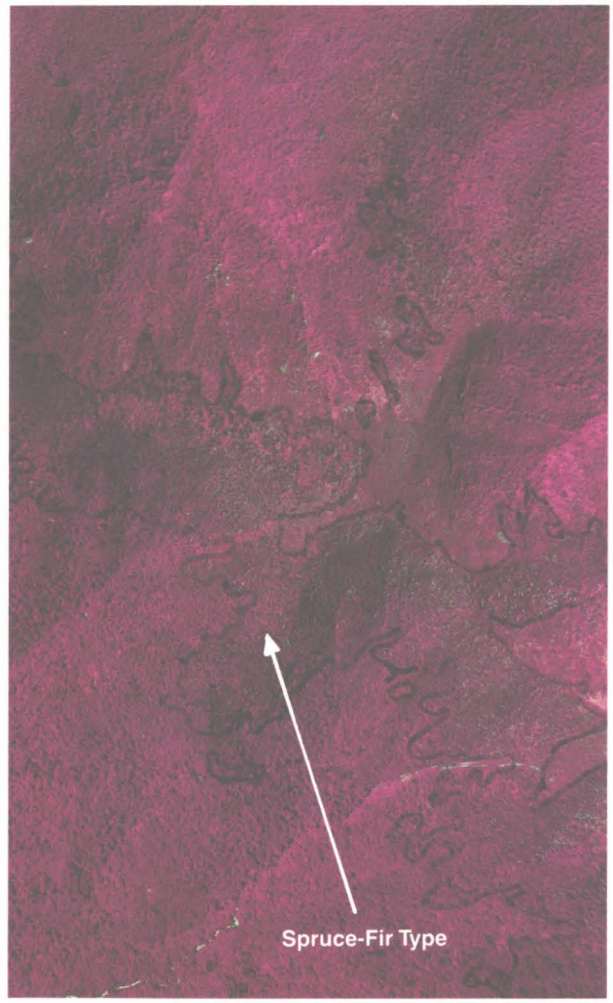


Figure 4.–Color infrared aerial photograph showing interpretation of spruce-fir forest type.

Although differentiating spruce from fir was not attempted in this evaluation, Ciesla and others (1986a) found that experienced photo interpreters could separate red spruce from Fraser fir 75% of the time and could classify healthy and declining trees with about 60% accuracy using a photo scale of 1:2,000. It was not practical to acquire this scale of aerial photography over large areas. Also, it was not possible to detect individual declining trees using the scale of photography acquired on the aerial survey.

Spruce-fir forests were interpreted into three mortality classes. These mortality classes differed from the classes used in other survey areas in the Northeast and West Virginia. These classifications reflect the high levels of Fraser fir mortality caused by the introduction of the balsam woolly adelgid into the Southeast.

A strong agreement between the ground survey versus the aerial photo interpretation was found for the mortality correlations (Table 3). Fixed plots measured trees not visible on the photography and were not considered in the correlation.

Table 3.—Spruce-fir mortality correlations for Ground survey vs. aerial photo interpretation

Location	# Plots*	R^2
Black Mountains	19	.80
Roan Mt.	19	.77
Balsam Mountains	20	.82
Great Smoky Mt. NP	16	.78

* Variable size plot (37.5 BAF) with > 10 trees per plot

Analysis of Data and Review of Cartographic Products

Data were analyzed by geographic area of spruce-fir in the southern Appalachians as follows: (1) Great Smoky Mountains National Park; (2) Balsam Mountains; (3) Roan Mountain; (4) Grandfather Mountain; (5) Mount Rogers/White Top Mountain; and (6) Black Mountains. Data were also compiled to summarize combined conditions throughout the southern Appalachians. Conditions are variable by geographic region and will be discussed separately for each of the six areas.

Acreage determinations for the spruce-fir type in the southern Appalachians were determined for each geographic area containing spruce-fir type. Acreages of tree mortality classes were determined. The relationship of the mortality classifications to topography were also analyzed. Spruce-fir type in relation to ownership was determined for each geographic area. Disturbance histories and previous histories of balsam woolly adelgid were reviewed for each geographic area. Volume loss estimates were determined for the four geographic areas where ground samples were taken.

Combined Results for Six Geographic Areas

The distribution of spruce-fir forests in the southern Appalachians is shown in figure 5. Maps contained in this document are at various scales. The original resolution of all mapped data is at a scale of 1:24,000 with geographic control and graphic detail much greater than could be realized on small-scale maps.

Spruce-fir level of mortality for each geographic area is shown in table 4. **It should be noted that this survey is a one-point-in-time analysis of standing dead trees within the spruce-fir type and certainly not a measure of mortality over a period of time.** It is known that dead spruce or fir trees may stand for up to 20 years and still may be visible on aerial photographs. No comparable data were collected previously, so the trend in mortality cannot be determined without follow-up surveys. The data, however, collected do provide indications of past trends in tree mortality. Mortality in this survey is actually a point-in-time percentage of standing dead trees and not a rate function.

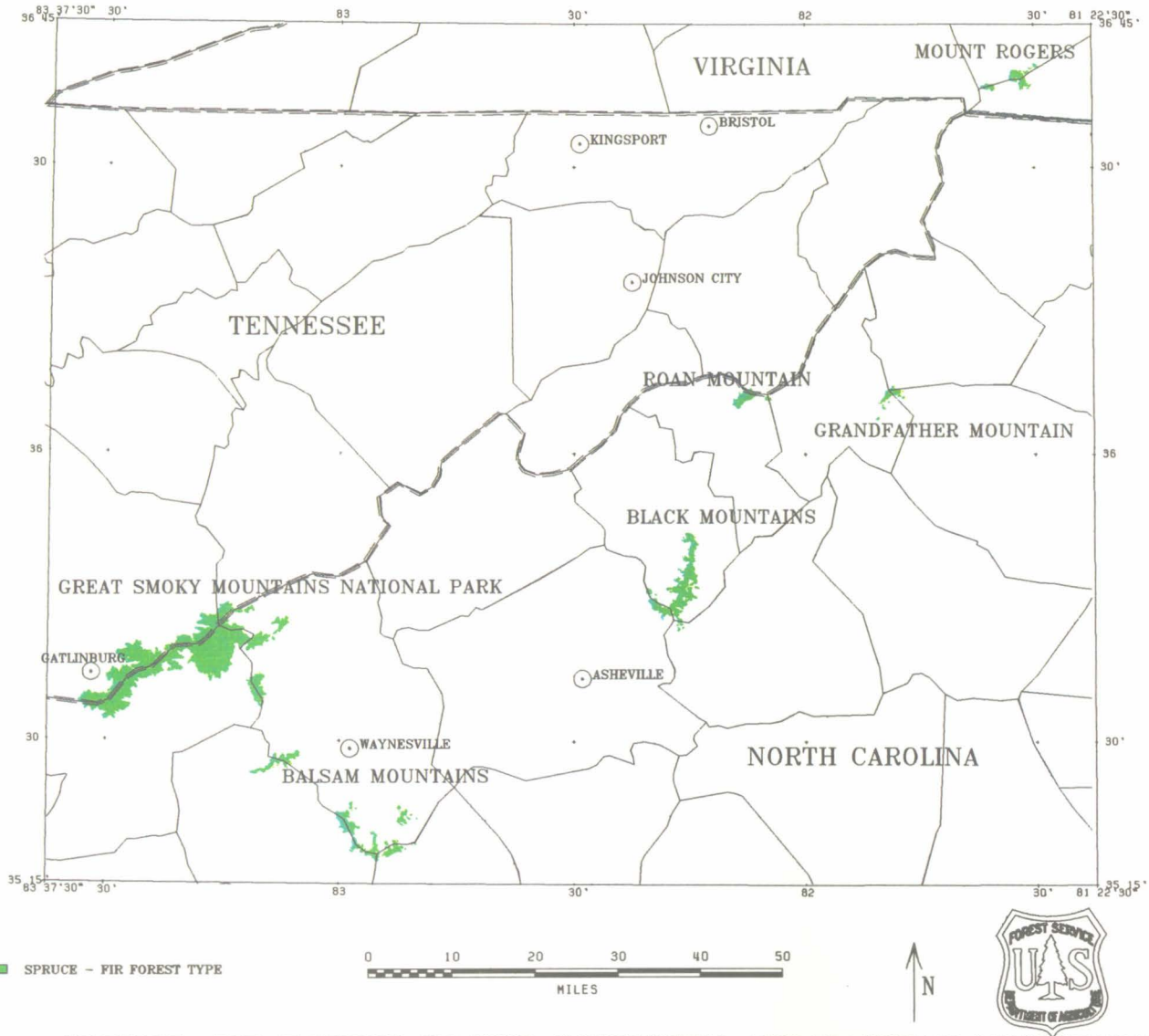


FIGURE 5 - SPRUCE–FIR FOREST IN THE SOUTHERN APPALACHIAN MOUNTAINS

TABLE 4--Spruce and Fir Forest in the Southern Appalachians, Classified by Level of Mortality

Geographic area	Mortality Classification: Light acres (hectares)	%	Heavy acres (hectares)	%	Severe acres (hectares)	%	Total acres (hectares)	%
Great Smoky Mountains National Park	35,664 (14,433)	73	2,692 (1,089)	6	10,365 (4,195)	21	48,721 (19,717)	74
Black Mountains	5,508 (2,229)	76	296 (120)	4	1,417 (573)	20	7,221 (2,922)	11
Roan Mountain	419 (170)	25	582 (236)	34	698 (282)	41	1,699 (688)	2
Mount Rogers/ White Top Mtn.	1,582 (640)	100	0 (0)		0 (0)		1,582 (640)	2
Grandfather Mtn.	659 (267)	71	124 (50)	13	145 (59)	16	928 (376)	1
Balsam Mountains	2,062 (834)	37	550 (223)	10	2,989 (1,210)	53	5,601 (2,267)	10
TOTAL	45,894	70	4,244	6	15,614	24	65,752	100

Light = 30% standing dead dominant and codominant trees
Heavy = 30 - 70% standing dead dominant and codominant trees
Severe = 70% standing dead dominant and codominant trees

A total of 65,752 acres (26,610 ha) of type was delineated with 24% classified as severe, 6% heavy, and 70% as light mortality (figure 6). The percentage of spruce-fir type by geographic area is shown in figure 7 and by State in figure 8. The majority (74%) of the type in the southern Appalachians is found in the Great Smoky Mountains National Park.

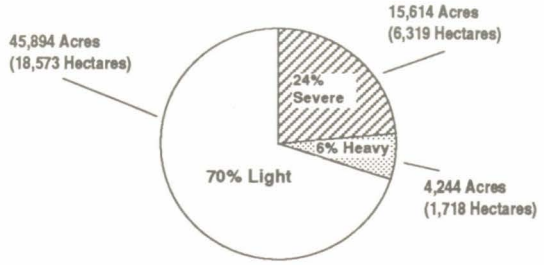


Figure 6.—Spruce-fir forest type in the southern Appalachian mountains classified by mortality.

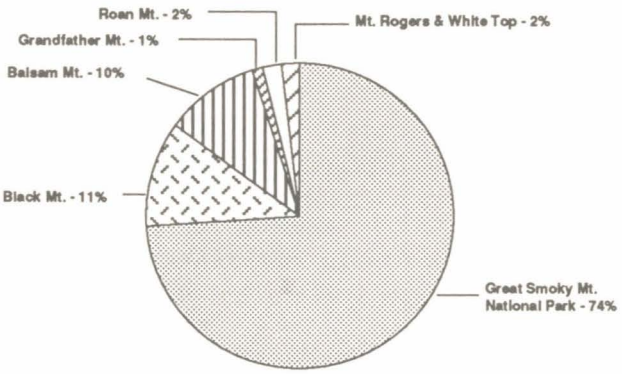


Figure 7.—Spruce-fir type in the southern Appalachian mountains by geographic area.

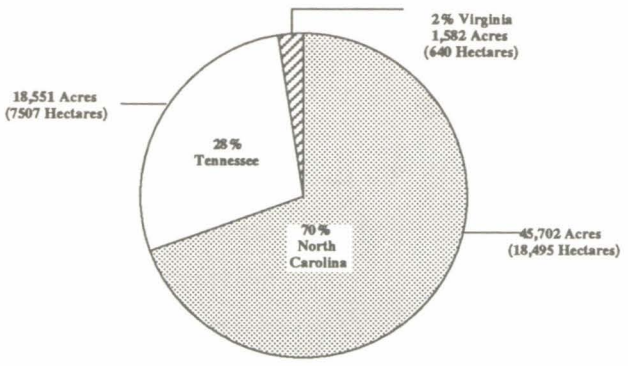


Figure 8.—Spruce-fir forest type by state in the southern Appalachian mountains.

Table 5 shows the percentage of the total area of each region, with the mortality stratified by elevation. A relatively small land area is found above 6,400 feet (1,951 m). These areas, however, receive the greatest number of visitors and are most visible to the public. Percent of total area, by mortality class, is shown for each elevation strata in (figure 9). Mortality increases with elevation, as shown in figure 10, when expressed as a percentage of the total area occupied by mortality class at each of the four elevation strata.

Analysis of mortality from ground inventories revealed that fir mortality decreased with elevation while spruce mortality was variable (table 6). Overall for the four areas containing ground plots, red spruce mortality was 8% and Fraser fir mortality was 67%. The pattern of greatest Fraser fir mortality at lower elevations is consistent with reports of balsam woolly adelgid depredations (Ciesla and others 1965; Eagar 1978; Johnson 1980; Witter and Ragenovich 1986). Fraser fir is the most sensitive North American species of Abies to adelgid attack (Bryant 1974). Initial infestations were generally found at the lower elevational limits of Fraser fir. On mountains with a longer history of balsam woolly adelgid activity, dead trees occurred at low to mid-elevations. This was followed by a zone of heavy infestation intensity with increasing elevation to the summit (Eagar 1978).

Because of manpower constraints, we could not positively identify the presence or signs of balsam woolly adelgid on each tree (dead or alive) in a study plot. The presence of balsam woolly adelgid was recorded on a plot-by-plot basis. Therefore, correlations between balsam woolly adelgid and mortality were not determined. Circumstantial evidence overwhelmingly indicates, however, that the balsam woolly adelgid was the chief cause of mortality for Fraser fir. Red spruce mortality was not alarming in any area. Of all geographic areas, spruce mortality was greatest on the Black Mountains (14%). The percentage of spruce and fir in the stand component, by elevation, is shown in table 7. These data substantiate reports of increasing fir as elevation increases with changes in the forest canopy along elevational gradients with red

TABLE 5--Spruce and fir mortality in the southern Appalachian Mountains stratified by elevation

	Mortality (% of area)														
	<4600 ft (1402 m)			4600-5200 ft (1402-1585 m)			5200-5800 ft (1585-1768 m)			5800-6400 ft (1768-1951 m)			>6400 ft (1951 m)		
Geographic region	L	H	S	L	H	S	L	H	S	L	H	S	L	H	S
Great Smoky Mtn National Park	7	0	0	39	2	0	26	3	15	1	1	5	0	0	1
Black Mountains	4	0	0	22	0	0	29	1	2	19	3	16	1	0	3
Balsam Mountains	1	0	0	6	1	1	26	8	34	5	1	18	-	NA	-
Roan Mountain	0	0	0	1	1	0	10	16	24	5	22	21	-	NA	-
Grandfather Mountain	7	0	0	28	1	1	35	12	12	1	0	1	-	NA	-
Mount Rogers/ White Top	2	0	0	54	0	0	44	0	0	-	NA	-	-	NA	-
Spruce-fir type in the SE	7	0	0	34	1	1	25	3	13	4	2	9	0	0	1

L = < 30% mortality
H = 30-70% mortality
S = > 70% mortality

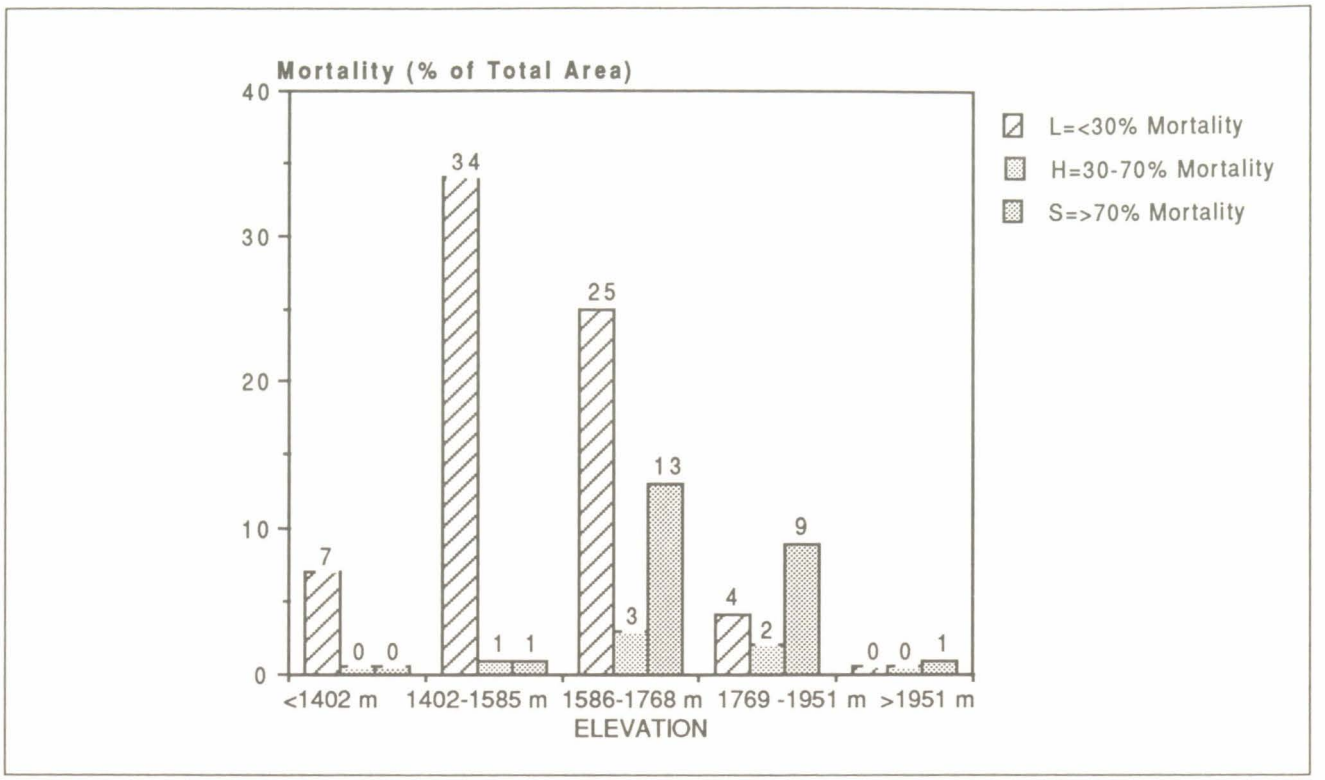


Figure 9.—Spruce-fir mortality in the southern Appalachian mountains, stratified by elevation.

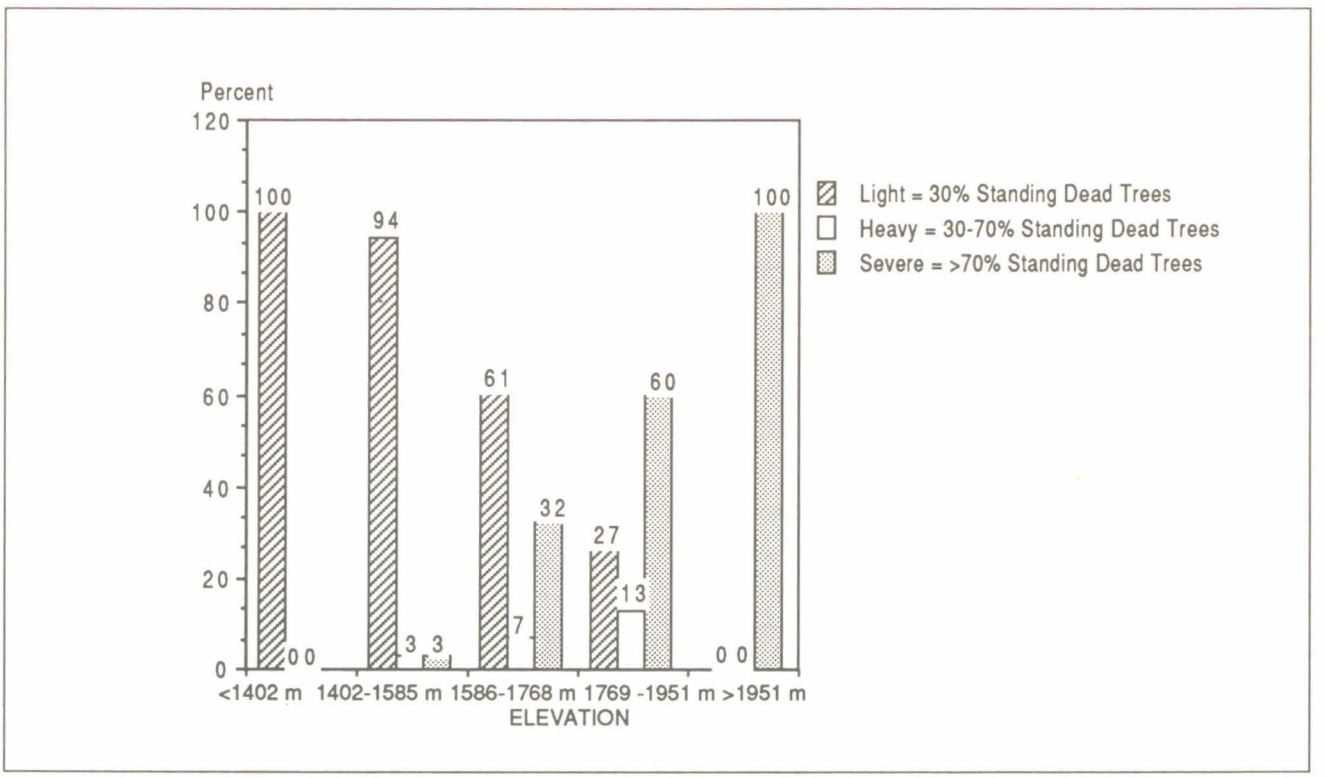


Figure 10.—Mortality classification as a percent of area occupied by elevation in the southern Appalachian mountains.

TABLE 6.--Results of ground survey for spruce-fir mortality in the southern Appalachian Mountains by elevation stratum

Area	4200-5400 ft (1280-1646 m)				5400-6000 ft (1646-1829 m)				6000-6500 ft (1829-1981 m)				Overall			
	Spruce		Fir		Spruce		Fir		Spruce		Fir		Spruce		Fir	
	N[1]	%[2]	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Black Mountains	102	10	4	100	83	13	57	23	18	39	54	72	203	14	115	49
Roan Mountain	17	6	27	67	83	1	181	50	16	13	129	30	116	3	337	44
Balsam Mountains	12	0*	14	0*	128	5	160	93	5	0*	3	0*	145	5	177	84
Great Smoky Mountain National Park	105	13	44	100	147	6	120	88	25	4	14	86	277	9	178	91

[1] N = No. of trees sampled

[2] Percentage of sampled trees dead

* = Insufficient sample size

TABLE 7.-- Spruce and fir forest type stand component in the southern Appalachian Mountains by elevation strata for ground survey samples

Area	4200-5400 ft (1280-1646 m)			5400-6000 ft (1646-1829 m)			6000-6500 ft (1829-1981 m)			Overall		
	S	F	Other	S	F	Other	S	F	Other	S	F	Other
	Percentage			Percentage			Percentage			Percentage		
Black Mountains	58	2	40	35	24	41	22	66	12	41	23	36
Roan Mountain	19	31	50	27	59	14	11	87	2	21	62	17
Balsam Mountains	21	24	55[1]	33	42	25	63	38	0[1]	32	39	29
Great Smoky Mountains National Park	52	22	26	43	36	21	64	36	0	48	3	21

1/ Insufficient sample size

S = Red spruce

F = Fraser fir

spruce dominant at lower elevations (Whittaker 1956; Schofield 1960; Ramseur 1960; White 1984; Groton 1985).

A small percentage of Fraser fir occupied the lower elevations and most of it was dead. The relationships of Fraser fir mortality and occurrence in relation to overall mortality is illustrated in figure 11.

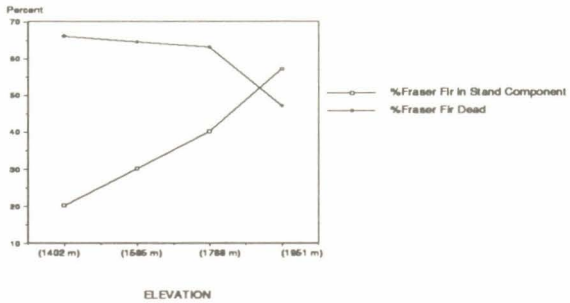


Figure 11.–Mortality classification, by elevation, in relation to Fraser fir mortality and percent of stand component in the southern Appalachian mountains.

Black Mountains

Mount Mitchell, in the Black Mountains, is the highest mountain in eastern North America, at 6,684 feet (2,037 m). The spruce-fir type occurs in the Pisgah National Forest, Blue Ridge Parkway, Asheville watershed, and Mount Mitchell State Park in Buncombe and Yancy counties, North Carolina. Mount Mitchell State Park was set aside in 1915 as North Carolina's first state park. The park was created to protect some of the virgin spruce-fir forest on the mountain, but the attrition of the virgin forest on the summit continued after park acquisition.

The balsam woolly adelgid has infested the entire range of the Black Mountains. Because of the radical change in the environment, even trees not directly injured by the adelgid will be affected in the Black Mountains (Pyle and others 1985).

Most of the mature fir in the Mount Mitchell area has died and there has been severe windthrow problems (figure 12). Patch blowdown of Fraser fir occurs on the highest summits. Some investigators refer to these as "fir waves"; other investigators state they lack regularity and orientation as described for northern fir waves (Reiners and others 1979, White 1984). Dense fir reproduction is present in disturbed areas (Johnson 1980, Witter and Ragenovich 1986). Bruck (1984 and 1985) has suggested that tree decline in the Black Mountains may be linked to atmospheric deposition.

Figure 12.–Aerial view of Mount Mitchell.

Spruce-fir area and mortality classification

A total of 7,221 acres (2,922 ha) of spruce-fir type were delineated on the Black Mountains, North Carolina. The type boundaries and the mortality classification within those boundaries are shown in figure 13. Seventy-six percent of the area was classified light; 4% heavy; 15% severe mortality; and 5% down timber (figure 14). The Black Mountains were the only area in the Southern Appalachians with relatively large areas of down timber.

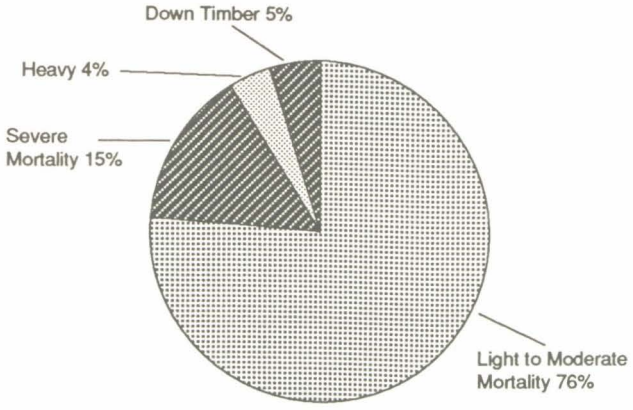


Figure 14.–Area impacted by Spruce-fir mortality on Black Mountains, NC.

Spruce and Fir Mortality in Relation to Elevation

Using an overlay to determine the relationship of the mortality classification to elevation, we found that increases in elevation showed an increase in mortality (figure 15). Although only 4% of the total spruce-fir type on Mount Mitchell is found above 6,400 feet (1,951 m), 59% of the total area above 6,400 feet (1,951 m) in elevation was classified as severe. Severe mortality was mapped on 42% of the total area between 5,800 and 6,400 feet (1,768 and 1,951 m), and only 6% of the total area was classified as severe between 5,200 and 5,800 feet (1,585 and 1,768 m). Below 5,200 feet (1,585 m) in elevation all spruce-fir mortality was classified as light.

On the Black Mountains, all of the Fraser fir below 5,400 feet (1,646 m) in elevation within the ground plots was dead (figure 16). Fraser fir, however, occupied only 2% of the stand component below 5,400 feet (1,646 m) (figure 17). Fraser fir and red spruce mortality increased with elevation on the Black Mountains. Percentage of fir in the stand component increased from 2% at the 4,200 to 5,400 feet (1,280 to 1,646 m) elevation up to 66% fir at the above 6,000 feet (1,829 m) stratum. Overall, 49% of Fraser fir was dead and 14% of the red spruce was dead. This was the highest percentage of spruce mortality for any geographic area in the southern Appalachians.

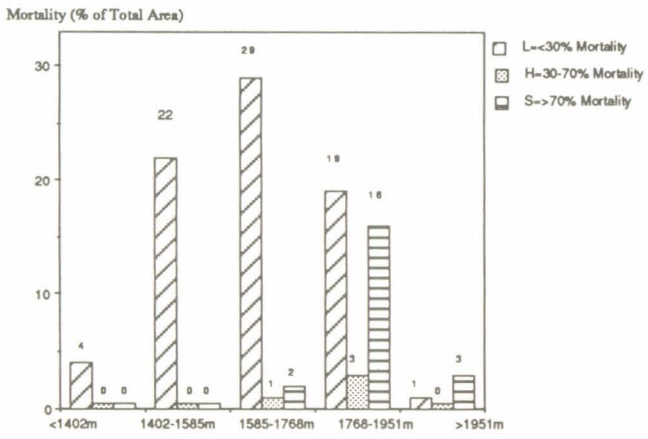


Figure 15.–Spruce-fir mortality (acres) stratified by elevation on Mount Mitchell.

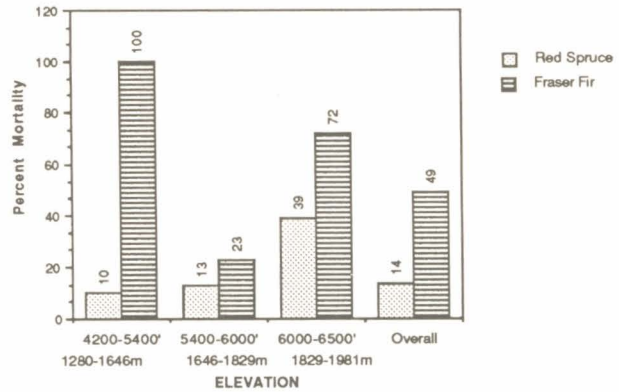


Figure 16.–Spruce-fir mortality (percent) stratified by elevation on Black Mountains from ground survey.

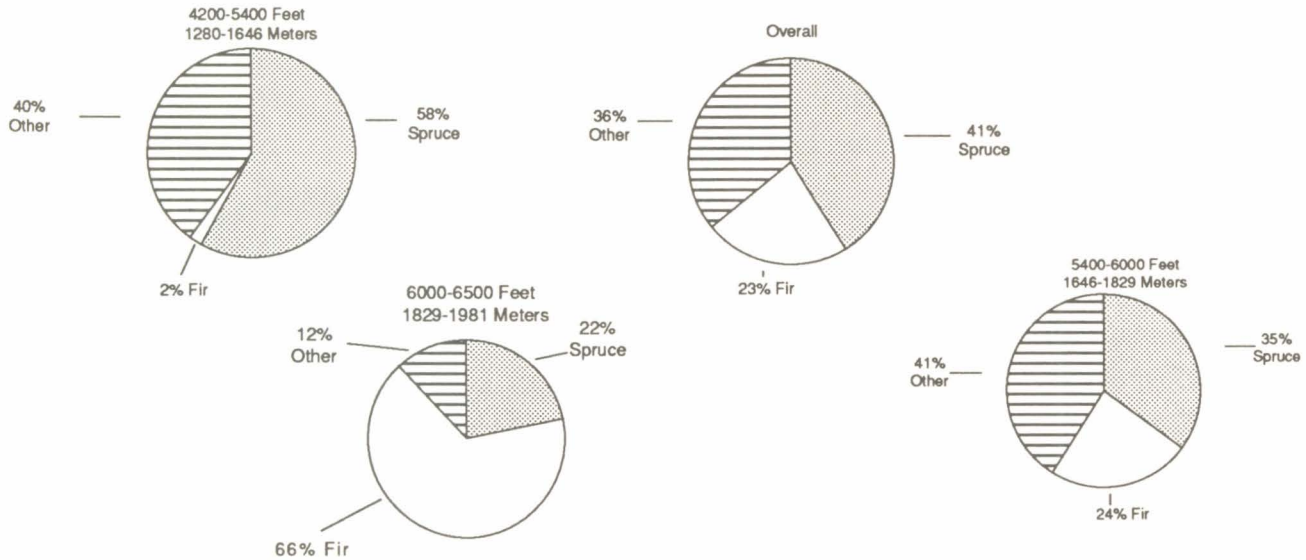
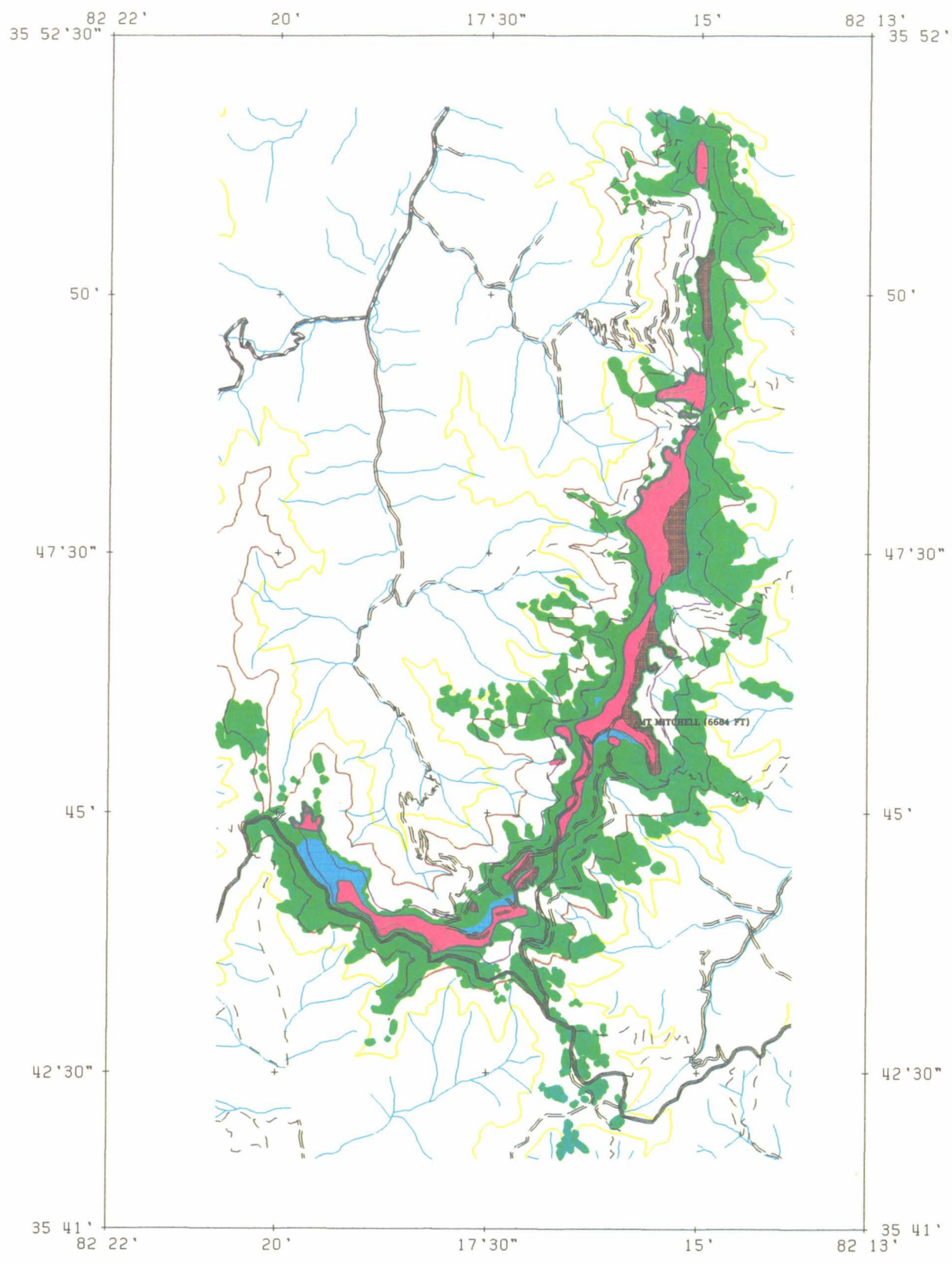


Figure 17.—Spruce-fir stand component classified by elevation for the Black Mountains from ground survey.



LEGEND

	PERCENT	ACRES	HECTARES
SEVERE MORTALITY (>70%.)	14.9	1071.0	433.4
HEAVY TO MODERATE MORTALITY (30-70%.)	4.1	296.0	119.4
LIGHT MORTALITY (<30%.)	76.3	5508.3	2229.0
DOWN TIMBER	4.7	345.7	139.9
TOTAL SPRUCE-FIR FOREST TYPE AREA		7221.0	2922.3

HEAVY-DUTY ROADS
MEDIUM-DUTY ROADS
IMPROVED ROADS
UNIMPROVED ROADS
TRAILS

6400 FOOT (1951 METER) CONTOUR LINE
5800 FOOT (1768 METER) CONTOUR LINE
5200 FOOT (1585 METER) CONTOUR LINE
4600 FOOT (1402 METER) CONTOUR LINE

NATIONAL FOREST BOUNDARY

STREAMS AND RIVERS

N

FOREST SERVICE
US
DEPARTMENT OF AGRICULTURE

FIGURE 13 - SPRUCE-FIR MORTALITY, BLACK MOUNTAINS, NC

Ownership Distribution in Relation to Mortality

Figure 18 shows the primary ownership patterns within the spruce-fir type on the Black Mountains. Fifty-one percent of spruce-fir type was within the national forest boundaries, 16% in the Mount Mitchell State Park, 6% on the Blue Ridge Parkway, and 27% within private land (figure 19). Figure 20 shows number of acres and percentage of mortality classification by ownership patterns on the Black Mountains. The Mount Mitchell State Park occupied areas at the highest elevation and displayed the highest percentage of area classified as severe mortality.

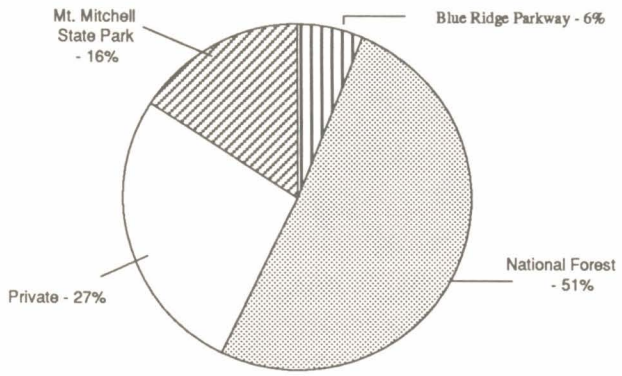


Figure 19.–Spruce-fir forest type on the Black Mountains, by ownership.

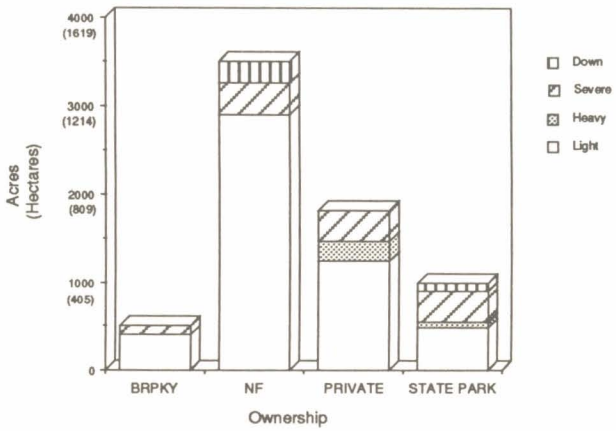


Figure 20.–Spruce-fir mortality, by ownership, on the Black Mountains.

Volume Losses

Cubic foot volume losses per acre, by condition and species for each elevation stratum from the variable plots on the Black Mountains, are shown in table 8. Figure 21 illustrates an inverse relationship between volume of spruce versus Fraser fir with increasing elevation. Red spruce decreases in volume per acre as elevation increases, whereas Fraser fir increases in volume per acre with an increase in elevation. A drastic increase in the volume of dead Fraser fir was found between the 5,400 to 6,000 feet (1646 to 1829 m) stratum and the 6,000 to 6,500 foot (1,829 to 1,981 m) elevation stratum. For all species, cubic-foot-per-acre volume decreased with increasing elevation.

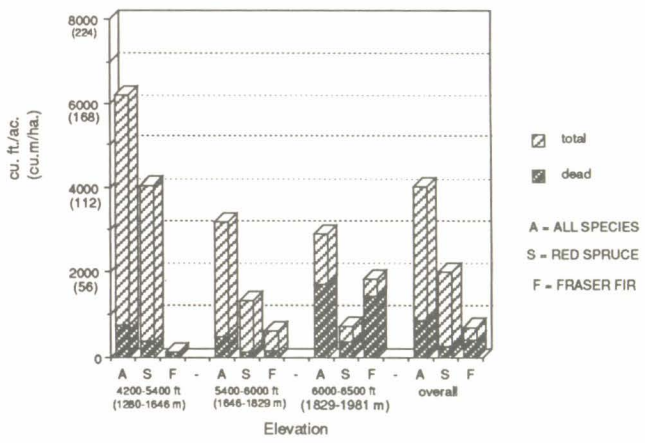


Figure 21.–Timber volume by elevation, on the Black Mountains.

The volume of spruce and fir by condition class is shown in figure 22. Dead timber contained 22% of the total spruce-fir volume. Sixty-one percent of the total Fraser fir volume was dead while 13% of red spruce volume on the Black Mountains was dead (figure 23).

Overall, based on 265 cubic feet (7 cubic meters) per acre for spruce and 416 cubic feet (12 cubic meters) per acre for fir, 1.9 million and 3.0 million total cubic feet of timber (53,200 and 84,000 cubic meters), respectively, were dead on the Black Mountains. For all species, a total of 6.4 million cubic feet of timber (179,200 cubic meters) was dead on the Black Mountains.

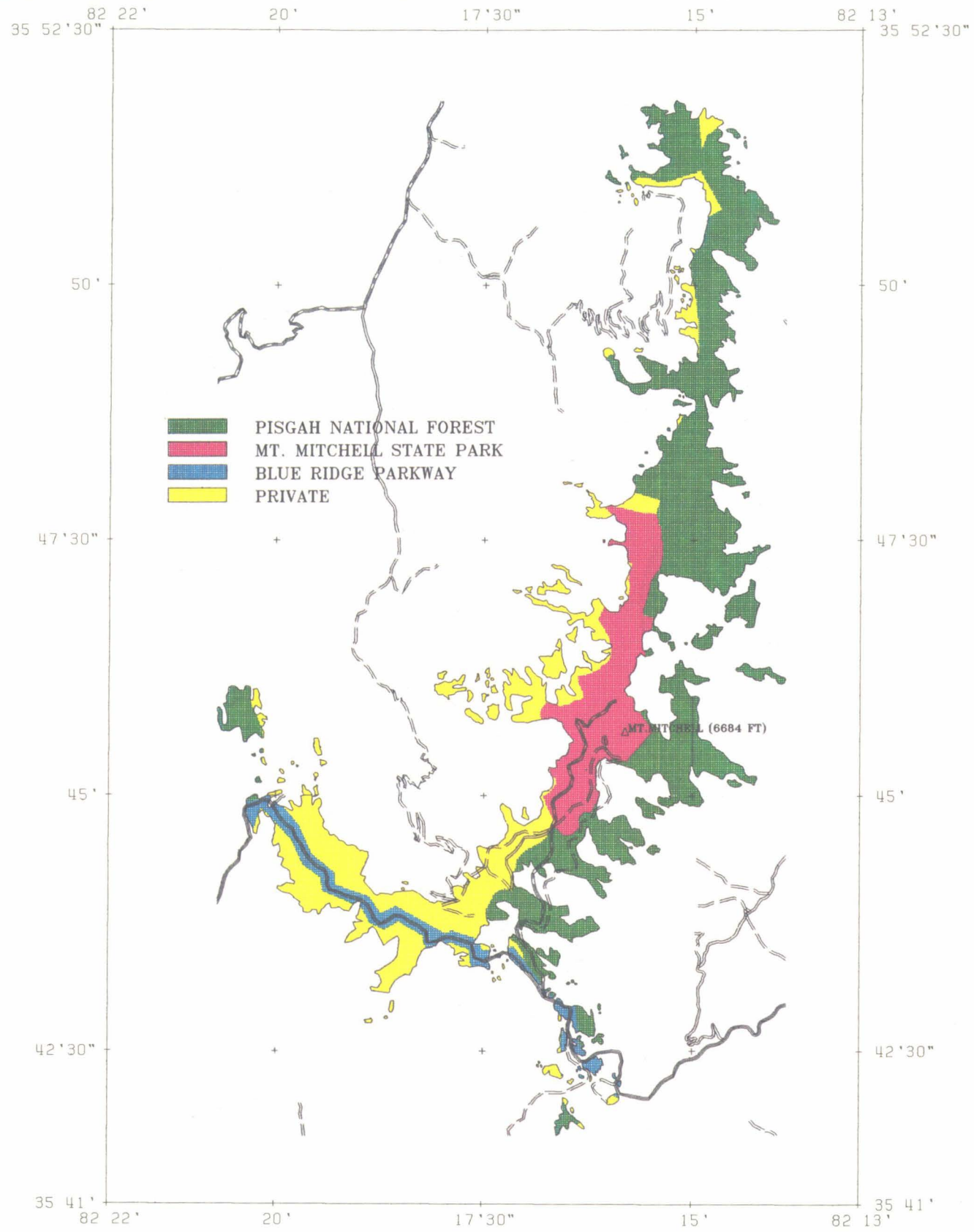


FIGURE 18

BLACK MOUNTAINS SPRUCE–FIR OWNERSHIP

Table 8.--Total ft^3 volume per acre by condition and species for elevation - Black Mountains, NC

	Elevation (ft)[m]											
	4200 - 5400 ft (1280 - 1646 m)			5400 - 6000 ft (1646 - 1829 m)			6000 - 6500 ft (1829 - 1981 m)			Overall		
Condition	S[1] (SE)	F[2] (SE)	ALL[3] (SE)	S(SE)	F(SE)	All (SE)	S(E)	F(SE)	All (SE)	S(SE)	F(SE)	All (SE)
Healthy ft	3583 (539)	0 (0)	5731 (690)	1165 (215)	430 (36)	2566 (331)	369 (228)	148 (20)	601 (240)	174 (197)	246 (18)	2988 (267)
meter	100 (15)	0 (0)	160 (19)	33 (6)	12 (1)	72 (9)	10 (6)	4 (1)	17 (7)	5 (6)	7 (1)	84 (8)
Declining ft	25 (1)	0 (0)	26 (21)	16 (0)	32 (16)	130 (28)	0 (0)	156 (40)	182 (41)	16 (1)	48 (11)	110 (17)
meter	.7 (.03)	0 (0)	.7 (.6)	.5 (0)	1 (.5)	4 (.8)	0 (0)	4 (1)	5 (1)	.5 (.03)	1 (.3)	3 (.5)
Dead ft	402 (166)	134 (45)	776 (244)	141 (30)	165 (14)	499 (93)	374 (147)	1431 (147)	2011 (246)	265 (59)	416 (34)	892 (100)
meter	11 (5)	4 (1)	22 (7)	4 (1)	5 (.4)	14 (3)	10 (4)	40 (4)	56 (7)	7 (2)	12 (1)	25 (3)
Down ft	41 (11)	0 (0)	41 (11)	0 (0)	0 (0)	0 (0)	0 (0)	108 (59)	108 (59)	12 (3)	22 (12)	34 (12)
meter	1 (5)	0 (0)	1 (.3)	0 (0)	0 (0)	0 (0)	0 (0)	3 (2)	3 (2)	.3 (.08)	.6 (.3)	1 (.3)
All Conds.	4051 (594)	134 (45)	6714 (767)	1322 (215)	627 (51)	3195 (358)	743 (275)	1843 (171)	2902 (376)	2007 (213)	732 (45)	4024 (298)
meter	113 (17)	4 (1)	188 (22)	37 (6)	18 (1)	90 (10)	21 (8)	52 (5)	81 (11)	56 (6)	21 (1)	113 (8)

1/ S = Red spruce
2/ F = Fraser fir
3/ SE = Standard Error

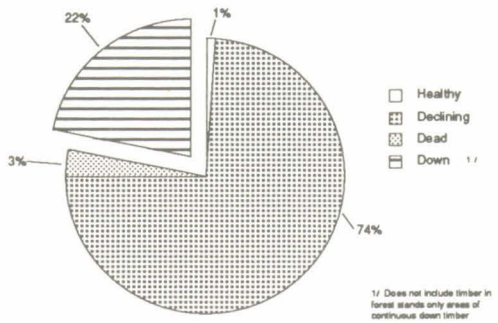


Figure 22.–Timber volume, by condition class, on the Black Mountains.

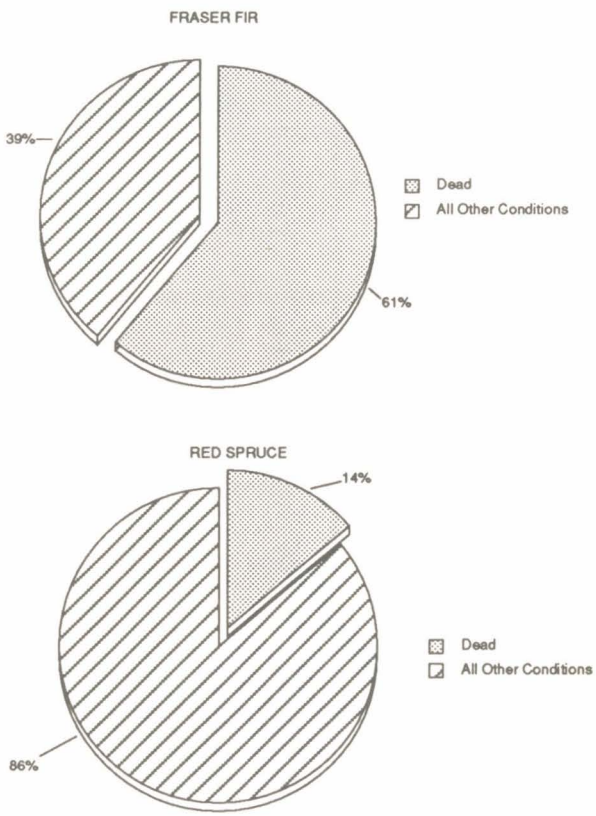


Figure 23.–Fraser fir and red spruce volume, by condition, on the Black Mountains.

Disturbance History

A disturbance history map developed by Pyle and others (1985) was overlaid on the spruce-fir type map delineated by the USDA Forest Service, Forest Pest Management (figure 24). Large areas that had been cut and burned appear to have caused a noticeable recession in the spruce-fir boundary on the south and east face of the mountain. Areas which were mapped as uncut and unburned on the northeast face of the mountain do not have the disturbances noted in the cut and burned areas on the south and east face. A strong relationship between the mortality classification and disturbance history was not observed (figure 25). Disturbance histories appear to have had a more profound effect on the boundaries and species composition of the spruce-fir type than upon current mortality classifications.

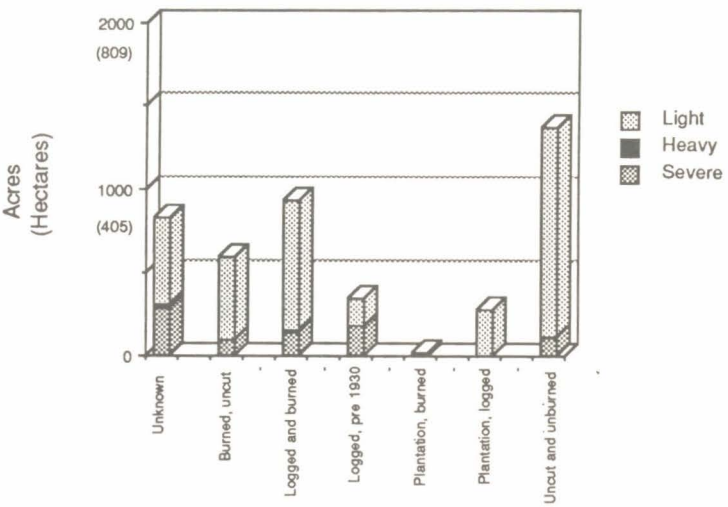


Figure 25.–Spruce-fir mortality, by disturbance, on the Black Mountains.

In 1967, Aldrich and Drooz published a map displaying the distribution of spruce-fir type and fir mortality caused by the balsam woolly adelgid, as of 1960. This map was photographically reproduced from the original publication at a 1:24,000 scale and transferred to the base map series. The original map and photograph from this earlier project could not be located. Mortality classes were combined to nearly coincide with the current mortality classes and overlaid (figure 26). Results of the overlay suggest that the type boundary has receded on the west and southwest aspects. Number of acres and percent of total acres by mortality class for both 1960 and 1984 are shown in figure 27. Areas classified with greater than 75% mortality have increased by a factor of 2.86 A loss of 3,700 acres (1,497 ha) of spruce-fir type has occurred since 1960 based upon the comparisons of these maps.

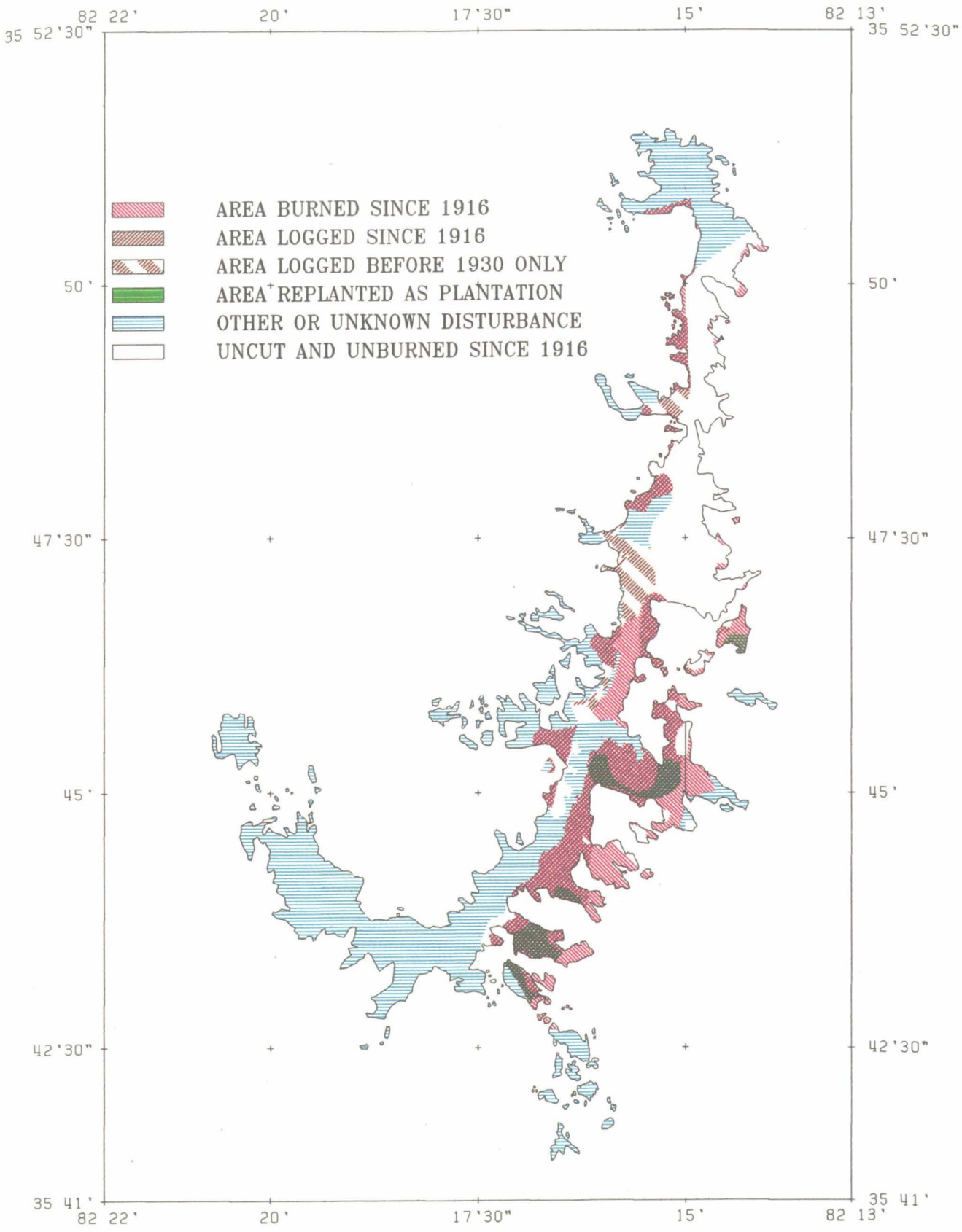


FIGURE 24

STAND HISTORY, BLACK MOUNTAIN, NC

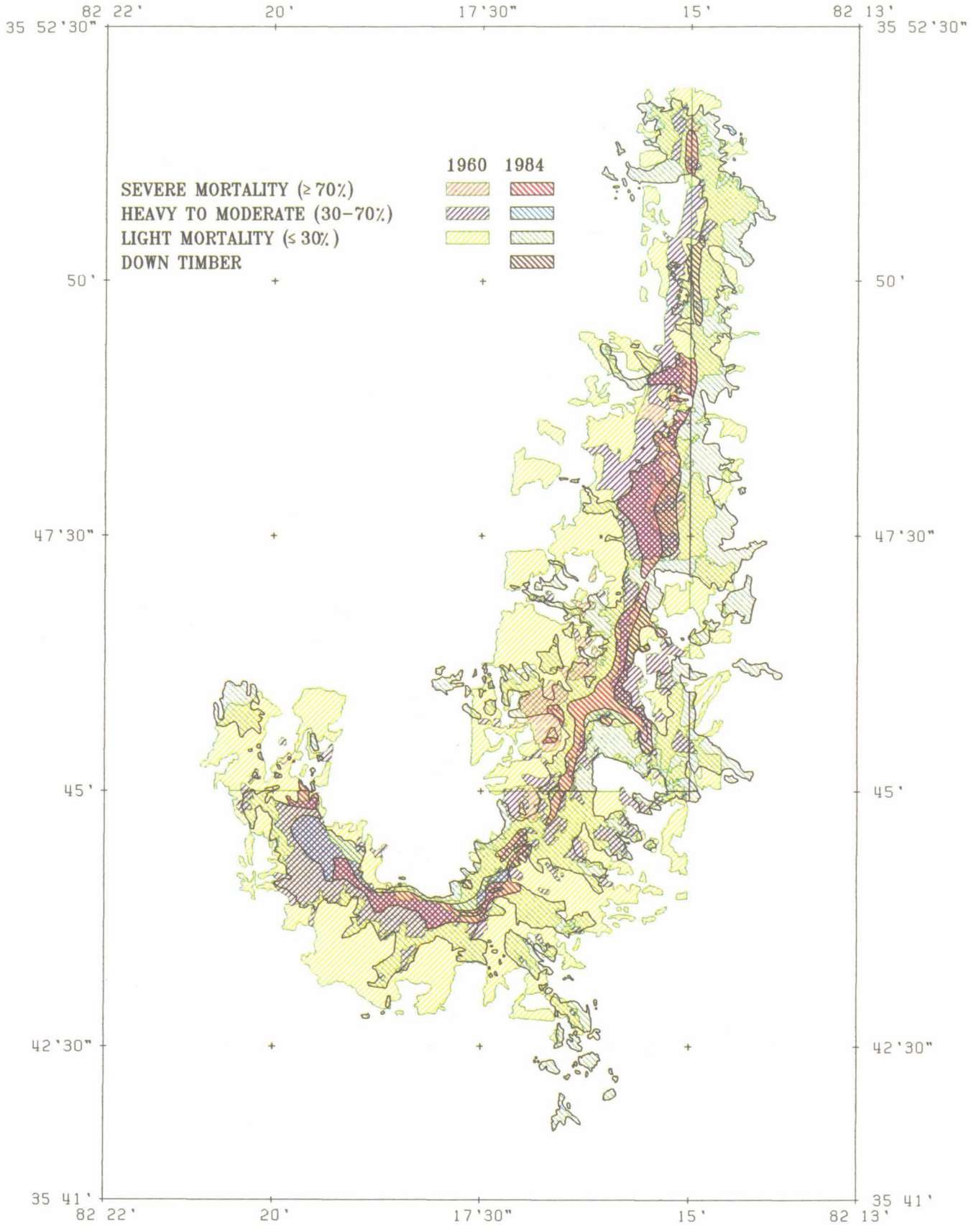


FIGURE 26

BLACK MOUNTAIN S MORTALITY, 1960 AND 1984

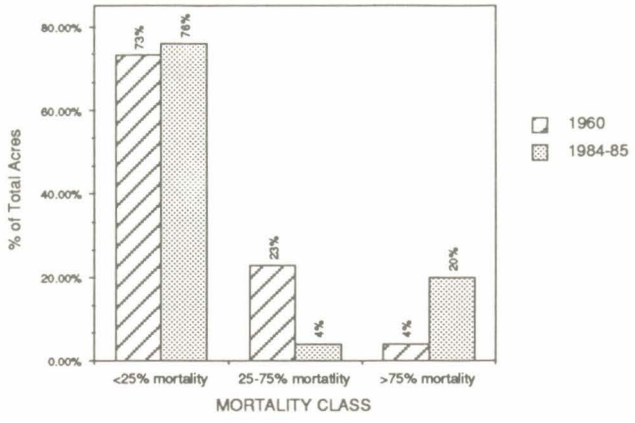


Figure 27.–Spruce-fir mortality, 1960 VS. 1984, on the Black Mountains.

Study Plot Locations

Figure 28 illustrates the locations of study plots established on Mount Mitchell. Study site locations provided by North Carolina State University and Virginia Polytechnical Institute and State University are also shown on this map, as well as the ground and air photo sample plots established by the USDA Forest Service, Forest Pest Management.

Balsam Woolly Adelgid History

Balsam woolly adelgid was first detected in the southern Appalachians on Mount Mitchell, North Carolina in 1957 (Speers 1958). Subsequent surveys revealed that the adelgid had spread throughout the entire Fraser fir type on Mount Mitchell (Nagel 1959). High mortality and widespread distribution indicated adelgid establishment prior to 1957, probably as early as 1940. The Mount Mitchell infestation then spread to the spruce-fir communities throughout the southern Appalachians.

An operational survey was conducted in 1962 (Ciesla 1962) of the adelgid infestations on Mount Mitchell State Park to determine which areas were in the greatest need of chemical suppression. During 1962, the area near Mount Mitchell was only very lightly infested and was not considered for chemical control.

Between 1962 and 1968, however, preventative type spraying was carried out on a 3-year rotation basis (Rauschenberger and Lambert 1968 and 1970). The protection area on Mount Mitchell State Park consisted of approximately 300 acres (121 ha) along a 2.5 mile (4 km) access road between the Blue Ridge Parkway and the crest of the Mountain. Trees were treated with 1/8% BHC spray, with about 1/3 of the protected area treated every third year.

In 1971, light infestations were found within the protection zone (Flavell and Lambert 1971). Treatment of the protection zone in the Mount Mitchell State Park continued annually until 1968, then again in 1972 and 1974. Spraying was discontinued after a study showed the BHC residues were persisting in the soil (Johnson 1980). The spruce-fir forests have been severely disturbed by balsam woolly adelgid, which has now killed most of the mature fir in the Black Mountains outside of the protection zone.

Witter and Ragenovich (1986) conducted surveys in 1966, and resurveyed in 1978, to measure mortality caused by the adelgid. In 1966, mortality on Fraser fir stems over 8 feet (244 cm) tall averaged 82, 88, and 95 percent in the fir, spruce-fir, and spruce-fir hardwood types, respectively. Witter stated that the number of dead Fraser fir stems from 1966 to 1978 had decreased about 3.5, 2.3, and 3.5 fold in the spruce, spruce-fir and spruce-fir/hardwood types, respectively, and that the Fraser fir would continue to exist as a species in the Mount Mitchell area.

Great Smoky Mountains National Park

The Great Smoky Mountains are in eastern Tennessee and western North Carolina between the cities of Knoxville on the west and Asheville on the east. The Great Smoky Mountains include some of the highest land east of the Mississippi River. For 36 miles (67 km) the main divide stands more than 5,000 feet (1,524 m) above sea level and 16 of the peaks rise to altitudes greater than 6,000 feet (1,829 m) with Clingman's Dome, the highest point in Tennessee, at 6,643 feet (2,025 m).

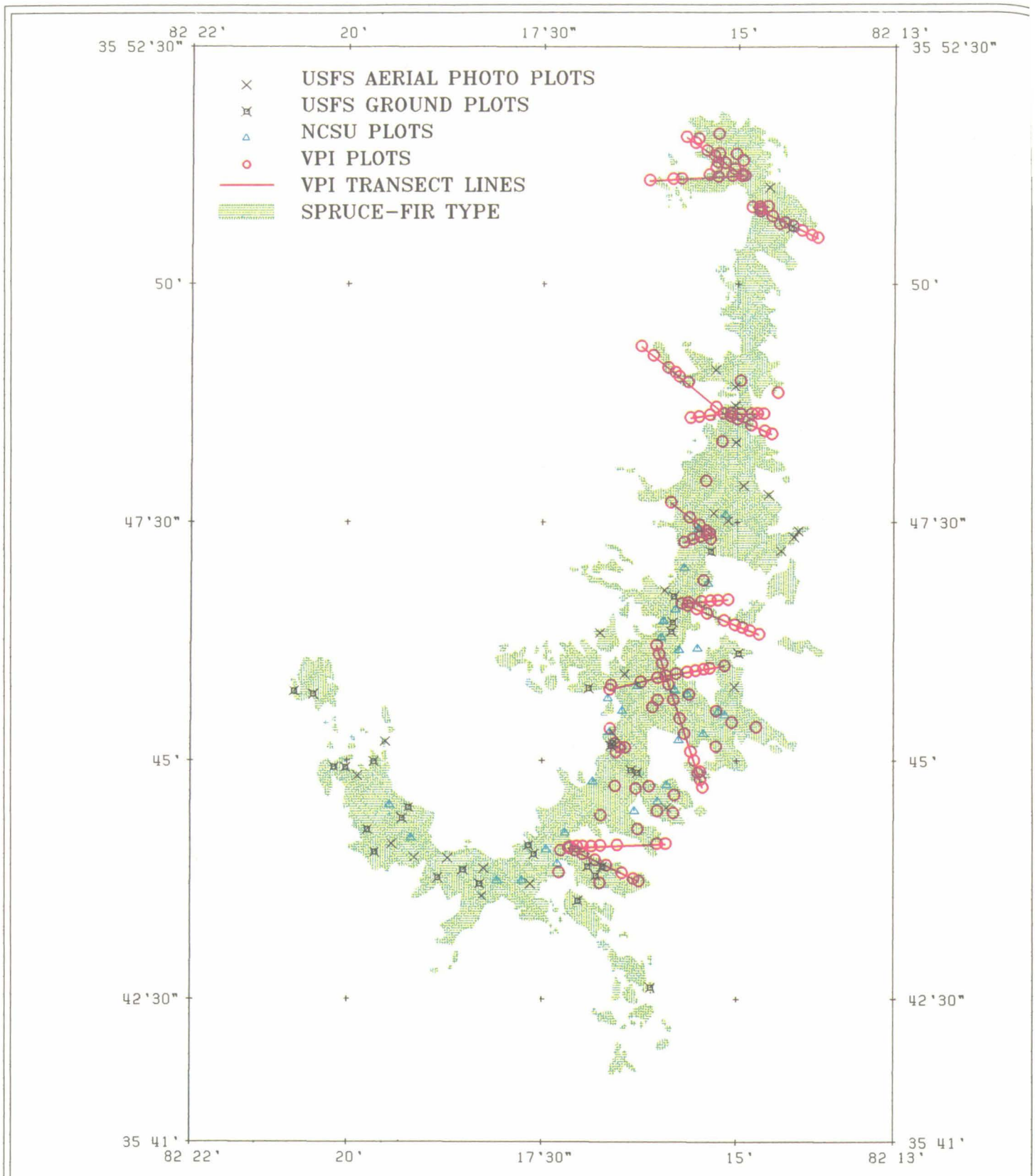


FIGURE 28

STUDY PLOT LOCATIONS, BLACK MOUNTAINS

The establishment of the park was authorized by Congress in 1926. The park is 54 miles (1,002 km) long and its greatest width is 19 miles (35 km). The total area of the park is about 500,000 acres (20,235 ha) or 780 square miles (2,020 sq km). The Appalachian Trail covers over 60 miles (111 km) within the park, much of which is located in the spruce-fir type. The Great Smoky Mountains National Park has one of the highest visitation rates of all national parks in the United States.

Spruce-fir Area and Mortality Classification

The spruce-fir type in the Great Smoky Mountains National Park occupied a greater area, 48,721 acres (19,717 ha), than all of the other geographic areas combined. The location of the type and the mortality classification within the type are illustrated in figure 29. Within the spruce-fir type, 21% was classified as severe mortality, 6% heavy mortality, and 73% light mortality (figure 30). Spruce-fir forest type maps were produced from the photo interpretation by Chris Eagar (National Park Service, Great Smoky Mountains National Park) of color IR photography and plotted on 1:24,000 USGS topo sheets. These maps were provided to Forest Pest Management and entered as part of the digital data base to produce figure 31. This map illustrates the areas of spruce and fir in relation to other hardwood and conifer species at the higher elevations.

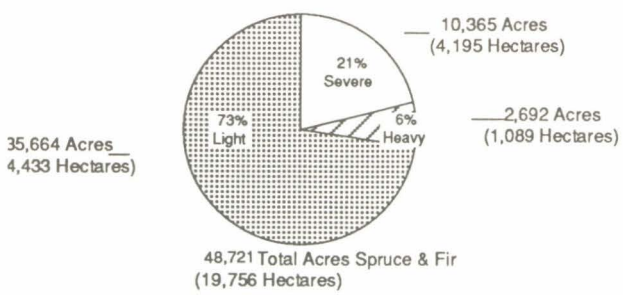


Figure 30.–Spruce-fir type on the Great Smoky Mountains National Park, classified by mortality.

Spruce and Fir mortality in Relation to Elevation

All of the spruce-fir type above 6,400 feet (1,951m) in elevation was classified as severe mortality. Severe mortality classification also occupied 71% of the area between 5,800 and 6,400 feet (1,768 and 1,951 m) in elevation. The percentage of the area classified as severe, within each elevation stratum, increased with increasing elevation (figure 32).

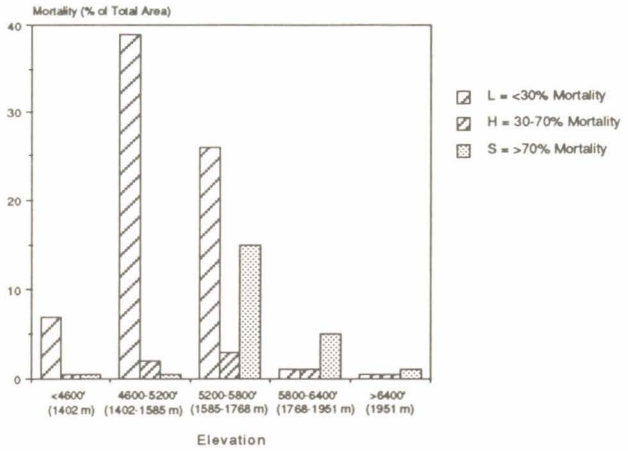


Figure 32.–Spruce-fir mortality, stratified by elevation, on the Great Smoky Mountains National Park.

The percentage of mortality of spruce and fir decreases slightly with increasing elevation. A drastic difference in the percentage of mortality, however, was found between spruce and fir within the park. Overall mortality was 91% for Fraser fir as opposed to only 9% for red spruce (figure 33). The percentage of Fraser fir within the stand component increased with elevation although not as dramatically as in other geographic regions. The percentages of spruce within the stand varied by elevation (figure 34). High percentage of spruce within the stand component at all elevations is probably the result of the large amounts of fir mortality observed within the park and a lack of logging within the virgin forest areas. All of the spruce-fir type within the Smoky Mountains is contained within the park.

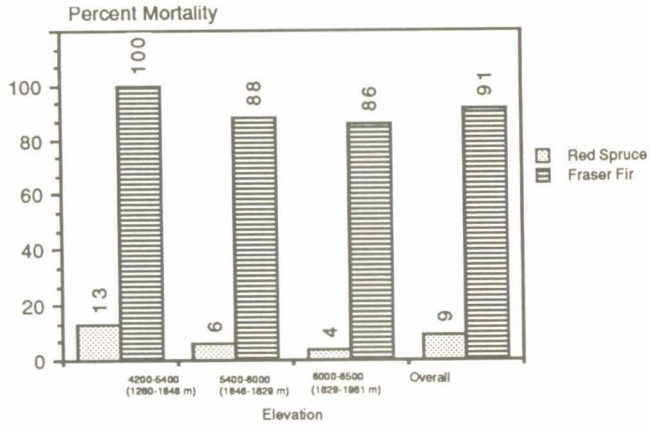


Figure 33.–Spruce-fir mortiality percent, by elevation, on the Great Smoky Mountains National Park, by ground truth.

Timber Volume Within the Spruce-fir Type

Table 9 shows the total cubic foot volumes per acre by condition class and species for each elevation stratum within The Great Smoky Mountains National Park. Spruce volume was greater than fir volume at all elevations. Cubic foot volume per acre for both spruce and fir increased with increasing elevation (figure 35). Ninety-one percent of the Fraser fir volume was classified as dead; a total of 8% of the spruce volume was classified as dead (figure 36). For all species, 34% of the total volume was classified as dead, 5% as declining, and 61% as healthy (figure 37).

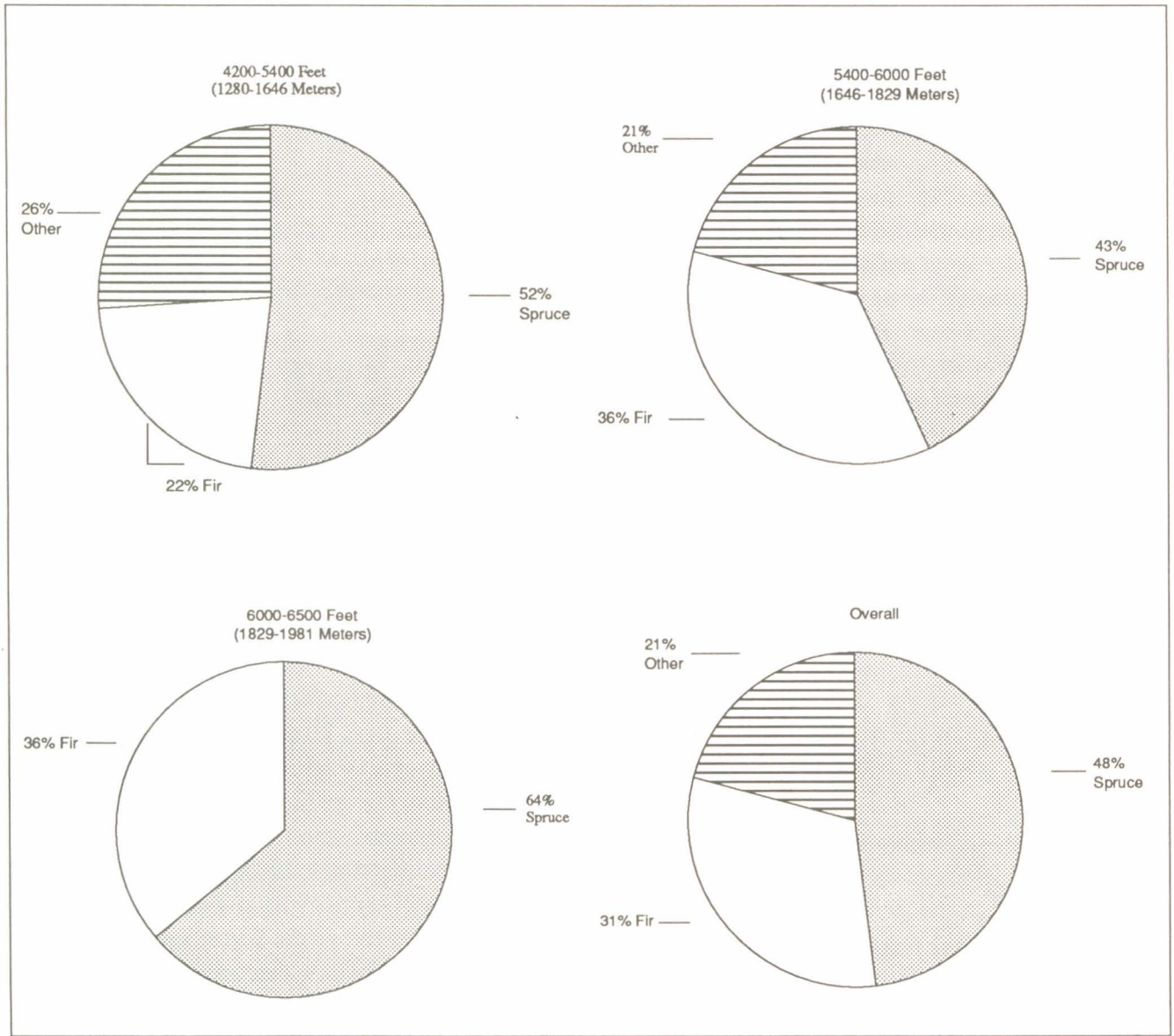
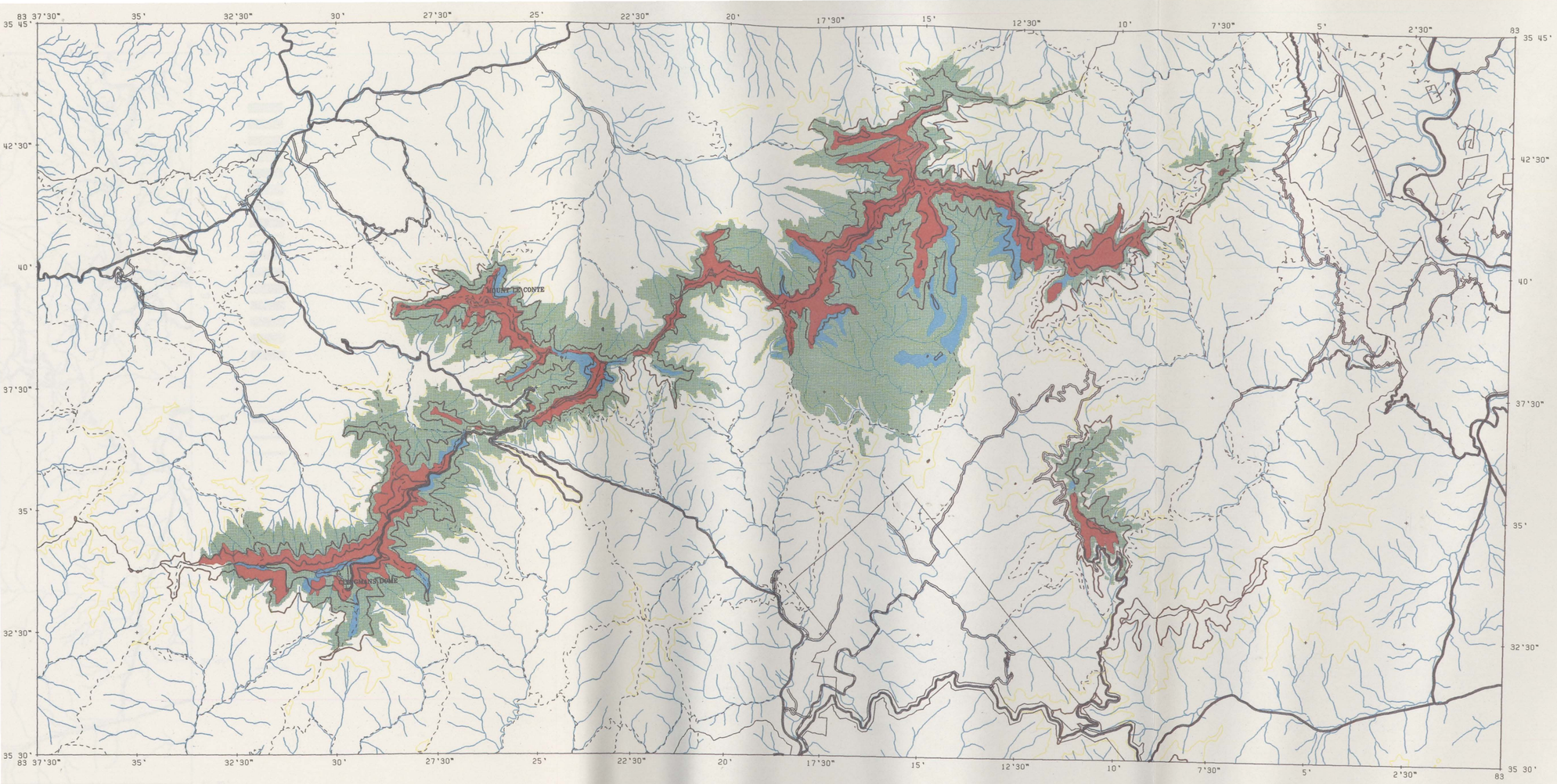


Figure 34.—Spruce-fir stand component classified by elevation on the Great Smoky Mountain National Park, from ground survey.



LEGEND

	PERCENT	ACRES	HECTARES
SEVERE MORTALITY (>70%.)	21	10365	14433.0
HEAVY TO MODERATE MORTALITY (30-70%.)	6	2692	1089.4
LIGHT MORTALITY (<30%.)	73	35664	4194.7
TOTAL SPRUCE-FIR FOREST TYPE AREA		48721	19717.1

- HEAVY-DUTY ROADS
- MEDIUM-DUTY ROADS
- IMPROVED ROADS
- UNIMPROVED ROADS
- TRAILS

- 6400 FOOT(1951 METER) CONTOUR LINE
- 5800 FOOT(1768 METER) CONTOUR LINE
- 5200 FOOT(1585 METER) CONTOUR LINE
- 4600 FOOT(1402 METER) CONTOUR LINE

- STREAMS AND RIVERS

N

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

0 1 2 3 4
MILES

FIGURE 29- SPRUCE-FIR MORTALITY, GREAT SMOKY MT. NATIONAL PARK

Table 9.--Total ft^3 volume per acre by condition and species for elevation - Great Smoky Mountains National Park

	Elevation (ft)[m]											
	4200 - 5400 ft (1280 - 1646 m)			5400 - 6000 ft (1646 - 1829 m)			6000 - 6500 ft (1829 - 1981 m)			Overall		
Condition	S[1] (SE)	F[2] (SE)	ALL[3] (SE)	S(SE)	F(SE)	All (SE)	S(E)	F(SE)	All (SE)	S(SE)	F(SE)	All (SE)
Healthy ft	2801 (311)	0 (0)	3847 (427)	2908 (268)	226 (60)	4226 (415)	6637 (1375)	0 (0)	6637 (1375)	3019 (203)	130 (34)	4179 (295)
meter	78 (9)	0 (0)	108 (12)	81 (8)	6 (2)	118 (12)	186 (39)	0 (0)	186 (39)	85 (6)	4 (1)	117 (8)
Declining ft	122 (111)	0 (0)	361 (165)	126 (56)	66 (17)	325 (131)	227 (2)	609 (24)	886 (130)	131 (53)	63 (10)	362 (98)
meter	3 (3)	0 (0)	10 (5)	4 (2)	2 (.5)	9 (4)	6 (.06)	17 (.7)	25 (4)	4 (2)	2 (.3)	10 (3)
Dead ft	419 (74)	1545 (143)	1963 (189)	190 (30)	2140 (149)	2384 (191)	292 (2)	4710 (676)	5003 (1045)	282 (33)	2017 (106)	2329 (138)
meter	12 (2)	43 (4)	55 (5)	5 (1)	60 (4)	67 (5)	8 (.06)	132 (19)	140 (29)	8 (1)	57 (3)	65 (4)
Down ft	0 (0)	0 (0)	32 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	12 (0)
meter	0 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.3 (0)
All Conds.	3342 (339)	1545 (143)	6203 (551)	3224 (275)	2432 (176)	6935 (491)	7206 (1659)	5319 (825)	12525 (2043)	3432 (216)	2210 (120)	6884 (363)
meter	94 (10)	43 (4)	174 (15)	90 (8)	68 (5)	194 (14)	202 (47)	149 (23)	351 (57)	96 (6)	62 (3)	193 (10)

[1] S = Red spruce
[2] F = Fraser fir
[3] SE = Standard Error

Replacement Page for Table 9; Page 47

Table 9.--Total ft^3 volume per acre by condition and species for elevation - Great Smoky Mountains National Park

	Elevation (ft)[m]											
	4200 - 5400 ft		00 - 6000 ft		6000 - 6500 ft		(1280 - 1646 m)			(1646 - 1829 m)			(1829 - 1981		
	m)|Overall				|Condition		S[1](SE)	F[2](SE)	All[3](SE)	S(SE)	F(SE)	All (SE)	S(SE)	F(SE)	All (SE)|
	S(SE)	F(SE)	All												
Healthy	ft	2801 (311)	0 (0)	3847 (427)		2908 (268)	226 (60)	4226 (415)	6637 (1375)	0 (0)	6637 (1375)	3019 (203)	130 (34)	4179 (295)	
	meter	78 (9)	0 (0)	108 (12)		81 (8)	6 (2)	118 (12)	186 (39)	0 (0)	186 (39)	85 (6)	4 (1)	117 (8)	
Declining	ft	122 (111)	0 (0)	361 (165)		126 (56)	66 (17)	325 (131)	227 (2)	609 (24)	886 (130)	131 (53)	63 (10)	362 (98)	
	meter	3 (3)	0 (0)	10 (5)		4 (2)	2 (.5)	9 (4)	6 (.06)	17 (.7)	25 (4)	4 (2)	2 (.3)	10 (3)	
Dead	ft	419 (74)	1545 (143)	1963 (189)		190 (30)	2140 (149)	2384 (191)	292 (2)	4710 (676)	5003 (1045)	282 (33)	2017 (106)	2329 (138)	
	meter	12 (2)	43 (4)	55 (5)		5 (1)	60 (4)	67 (5)	8 (.06)	132 (19)	140 (29)	8 (1)	57 (3)	65 (4)	
Down	ft	0 (0)	0 (0)	32 (0)		0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	12 (0)	
	meter	0 (0)	0 (0)	1 (0)		0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	.3 (0)	
All Conds.		3342 (339)	1545 (143)	6203 (551)		3224 (275)	2432 (176)	6935 (491)	7206 (1659)	5319 (825)	12525 (2043)	3432 (216)	2210 (120)	6884 (363)	
	meter	94 (10)	43 (4)	174 (15)		90 (8)	68 (5)	194 (14)	202 (47)	149 (23)	351 (57)	96 (6)	62 (3)	193 (10)	

[1] S = Red spruce
[2] F = Fraser fir
[3] SE = Standard Error

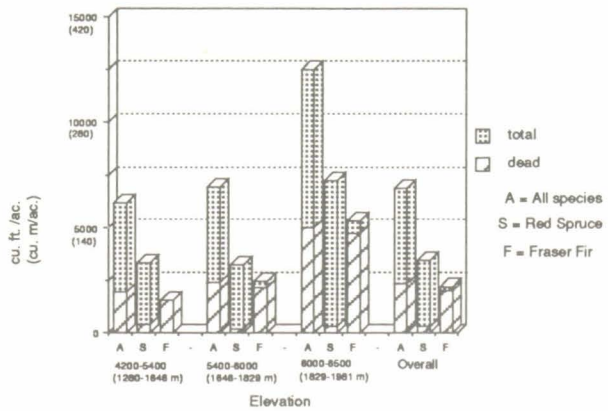


Figure 35.–Timber volume, by elevation, Great Smoky Mountains National Park.

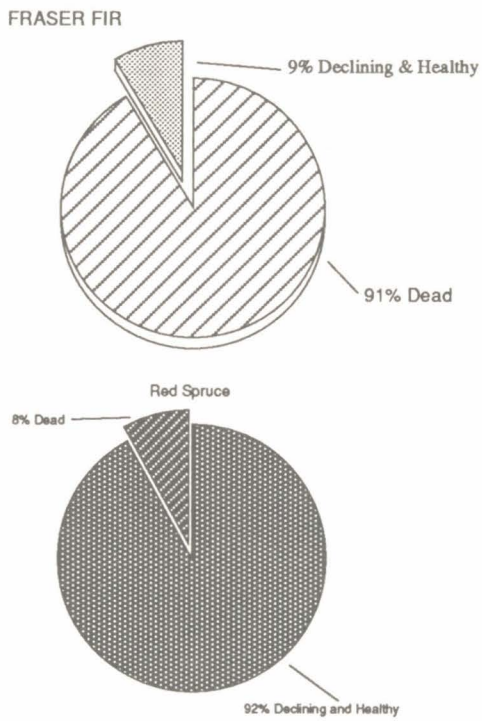


Figure 36.–Fraser fir and red spruce volume, by condition, on the Great Smoky Mountains National Park.

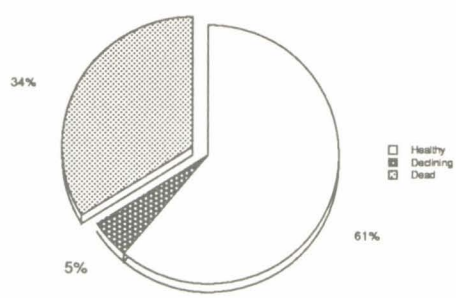


Figure 37.–Timber volume, by condition class, Great Smoky Mountains National Park.

Overall, 282 cubic feet (8 cubic meters) per acre were classified as dead for red spruce, which when expanded over the entire park, produces a volume estimate of 13.7 million cubic feet (383,600 cubic meters) of dead spruce timber. A total of 2,017 cubic feet (57 cubic meters) per acre for Fraser fir was found dead within the park, which when expanded over the entire spruce-fir type within the park, produces an estimated 98.3 million cubic feet (2,752,400 cubic meters) of dead Fraser fir.

Disturbance History

A disturbance history map for the SARRMC intensive study area (Newfound Gap to Mount Buckly) developed by Pyle and others (1985) was overlaid on the current spruce-fir mortality classification. A majority of the area was classified as uncut and unburned. Approximately the same percentages of severe and light mortality were found within all of the different disturbance classes (figure 38).

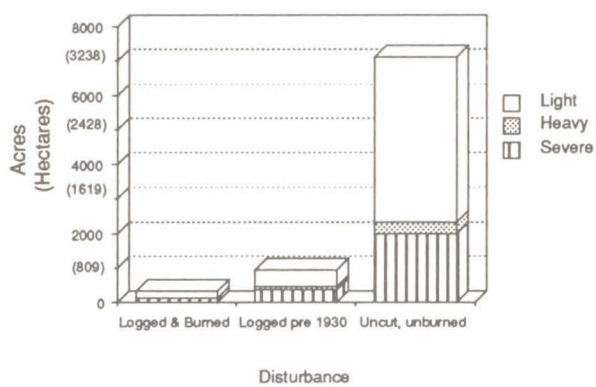


Figure 38.–Spruce fir mortality, by disturbance, Great Smoky Mountains National Park.

Balsam Woolly Adelgid History

In 1963, the balsam woolly adelgid was first detected in The Great Smoky Mountains National Park in the vicinity of Mount Sterling in North Carolina (Ciesla and others 1963). Subsequent aerial surveys in 1969 revealed hundreds of red and fading fir trees that had succumbed to the

adelgid. Two roadside areas of host fir stands were designated as protection areas on the park during 1969 (Raushenberger and Lambert 1970).

In 1971, even the protection zones were found to be infested (Flavel and Lambert 1971). Outside the protection zone, a moderate adelgid population was found. By 1978 the adelgids were present throughout the entire park. Eagar (1978) reported a pattern of infestation spread from lower to higher elevations. At the lower elevations along the hardwood ecozone, numerous and scattered infestations were found. As these expanded and merged, large infestations developed and convective winds disseminated the insects upslope. Again, mortality increased with elevation and increased in proportion to the percentage of Fraser fir in the stand component. Pyle (1984) reported that elevation and degree of past disturbance are the best predictors of expected fir mortality caused by balsam woolly adelgid in the Great Smokies because of a high proportion of Fraser fir in both high elevations and disturbed stands.

Maps displaying adelgid-caused mortality in 1976 over the Smokies compiled by Pyle and others (1985), when digitized, showed an acreage of only 25 acres (10 ha) classified with greater than 15% mortality. Maps over the same area for 1985 on two quad sheets (Clingman's Dome and Silers Bald) showed that the mortality had increased to 4,600 acres (1,862 ha) with greater than 30% mortality.

Infestations of balsam woolly adelgid have resulted in increased fuel loading in the Great Smoky Mountains spruce-fir vegetation (Nicholas and White 1985). At higher elevations within recently infested stands, standing dead basal area was four times higher, and down volumes were two times higher than unimpacted areas.

Study Plot Locations

The locations of FPM photo plots and ground plots within the Great Smoky Mountains National Park are shown in figure 39. Locations of the SARRMC intensive study sites established by the National Park and North Carolina State University are also shown in figure 39.

Roan Mountain

Roan Mountain is located in Pisgah and Cherokee National Forests in Carter County, Tennessee; and in Mitchell County, North Carolina. Roan High Knob rises to an elevation of 6,285 feet (1,916 m) while nearby Roan High Bluff stands at 6,267 feet (1,910 m). Visitation to this area has recently increased, especially during winter time with the popularity of cross-country skiing. The Appalachian Trail crosses through the spruce-fir type. During the early summer months, the Rhododendron Gardens are a popular stop for visitors. The development of the Roan Mountain State Park in Tennessee has also increased the number of visitors on Roan Mountain.

Spruce-fir Area and Mortality Classification

The location of the spruce-fir type and the classification within the type are shown in figure 40. Spruce-fir type occupied 1,699 acres (688 ha). Within the type, 41% was classified as severe mortality, 34% heavy, and 25% light (figure 41). An additional 163 acres (66 ha) of red spruce were delineated (at Beauty Spot, Tennessee) as light mortality subsequent to the initial survey.

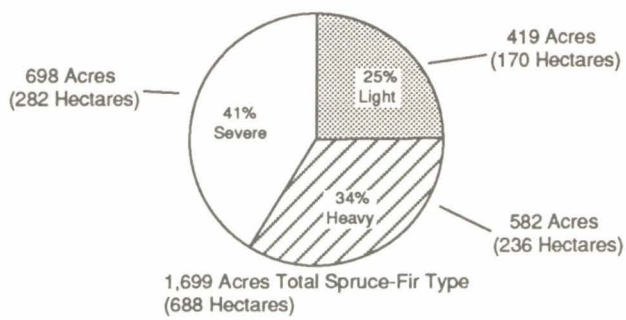


Figure 41.–Spruce-fir type (acres) on Roan Mountain, classified by mortality.

Spruce and Fir Mortality by Elevation

The spruce-fir mortality classification was overlaid and analyzed by the GIS in relation to

elevation (figure 42). At the 5,800 to 6,400 feet (1,768 to 1,951 m) elevation stratum, 21% of the total spruce-fir type area was classified as severe. At the 5,200 to 5,800 feet (1,585 to 1,768 m) stratum, 24% of the entire spruce-fir area on Roan Mountain was classified as severe mortality. Only 2% of the total spruce-fir type occurs below 5,200 feet (1,585 m). Above 5,800 feet (1,768 m), 749 acres (303 ha) of type were delineated. An area of 761 acres (308 ha) were found between 5,200 and 5,800 foot (1,585 to 1,768 m) contours. The remaining 26 acres (11 ha) were below 5,200 feet (1,585 m). These data do not show strong correlations between increasing mortality with increasing elevation because of the limited range across the elevation stratum. Figure 43 illustrates the percentage of the type by mortality at each elevation. Fir mortality decreased with increasing elevation while spruce mortality was variable across elevational stratum. Overall, 44% mortality was found in fir while only 3% mortality occurred in the spruce (figure 44). The occurrence of fir within the stand component increased with elevation while the percentage of spruce within the stand decreased with elevation (figure 45). Only 3% of the type, 49 acres (20 ha), was found to be held in private ownership.

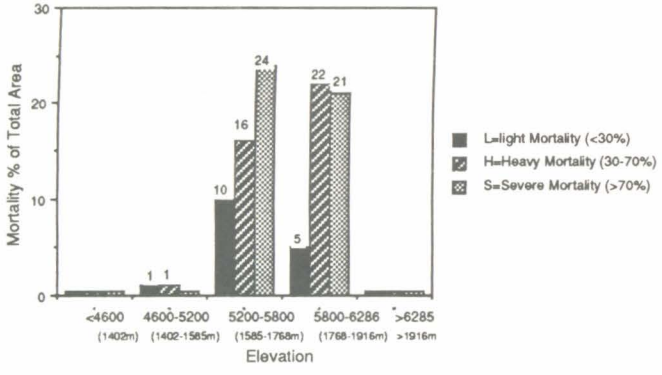


Figure 43.–Spruce-fir mortality (acres) stratified by elevation on Roan Mountain.

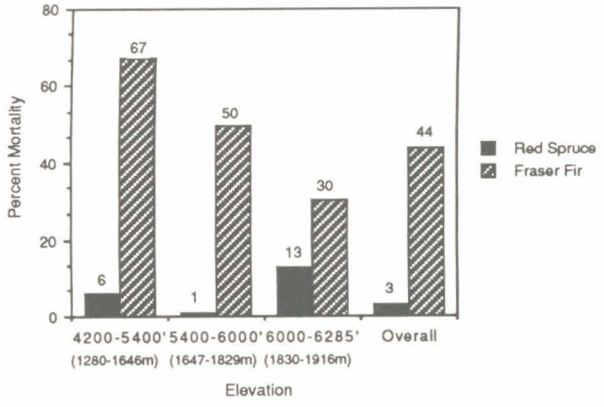


Figure 44.–Spruce-fir mortality (percent) by elevation on Roan Mountain from ground survey.

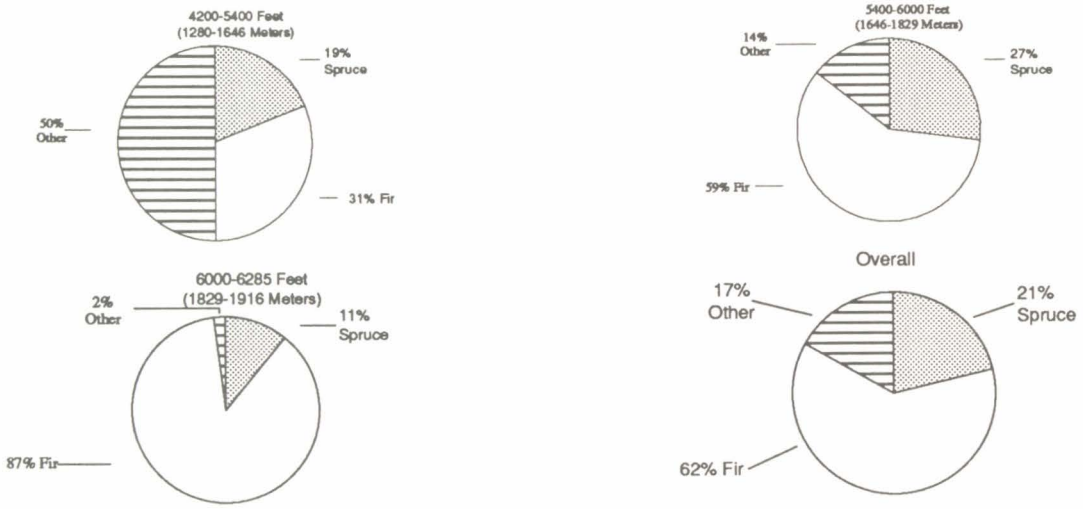


Figure 45.—Spruce-fir stand component, by elevation, for Roan Mountain.

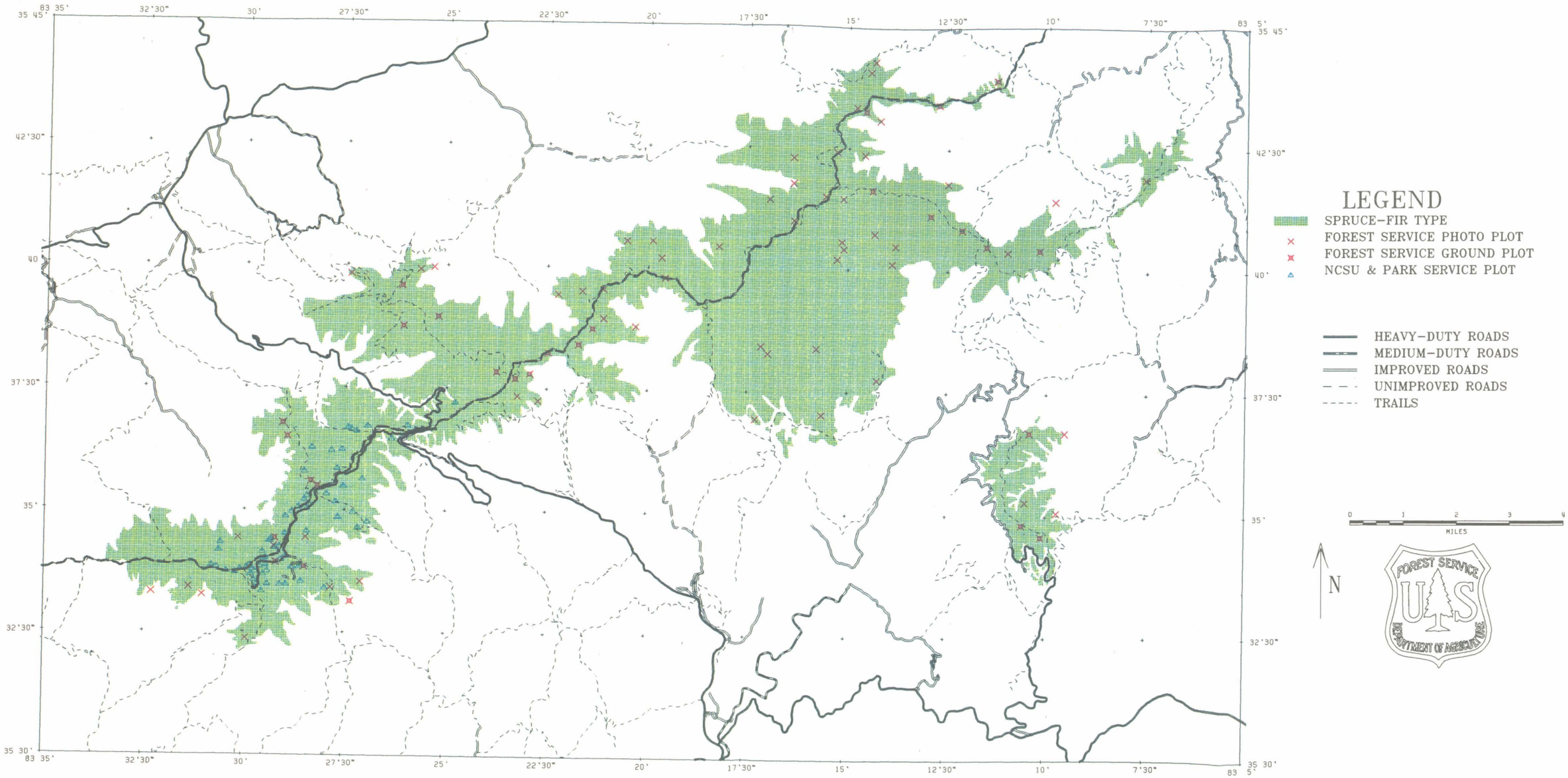
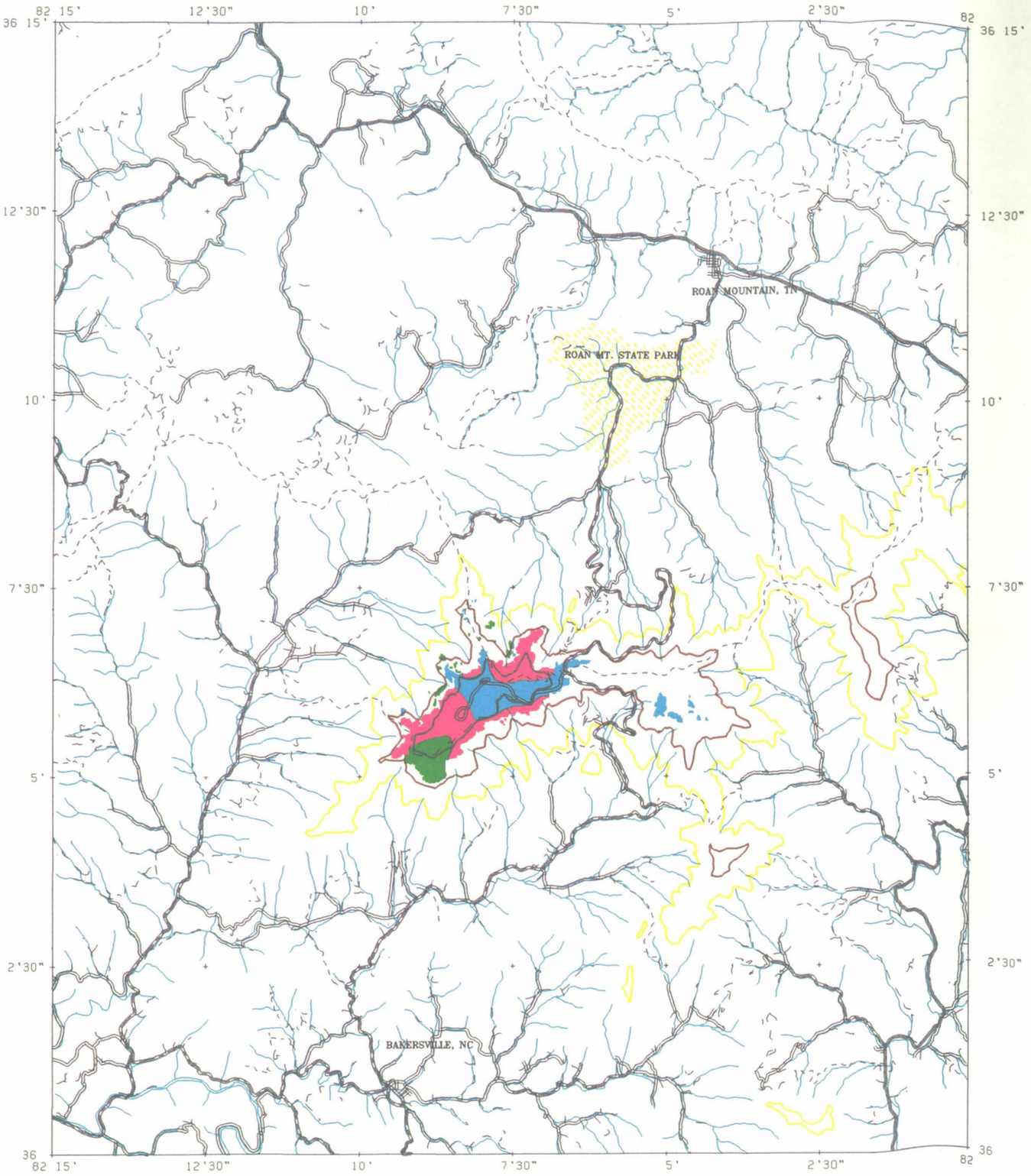


FIGURE 39– STUDY PLOT LOCATIONS, GREAT SMOKY MOUNTAINS NATIONAL PARK



LEGEND

	PERCENT	ACRES	HECTARES
SEVERE MORTALITY (>70%)	41	698	282
HEAVY TO MODERATE MORTALITY (30-70%)	34	582	236
LIGHT MORTALITY (<30%)	25	419	169
TOTAL SPRUCE-FIR FOREST TYPE AREA		1699	687

HEAVY-DUTY ROADS
MEDIUM-DUTY ROADS
IMPROVED ROADS
UNIMPROVED ROADS
TRAILS

6400 FOOT(1951 METER) CONTOUR LINE
5800 FOOT(1768 METER) CONTOUR LINE
5200 FOOT(1585 METER) CONTOUR LINE
4600 FOOT(1402 METER) CONTOUR LINE

STREAMS AND RIVERS

N

FOREST SERVICE
US
DEPARTMENT OF AGRICULTURE

0 1 2 3 4 5
MILES

FIGURE 40- SPRUCE-FIR MORTALITY, ROAN MT., NC & TN

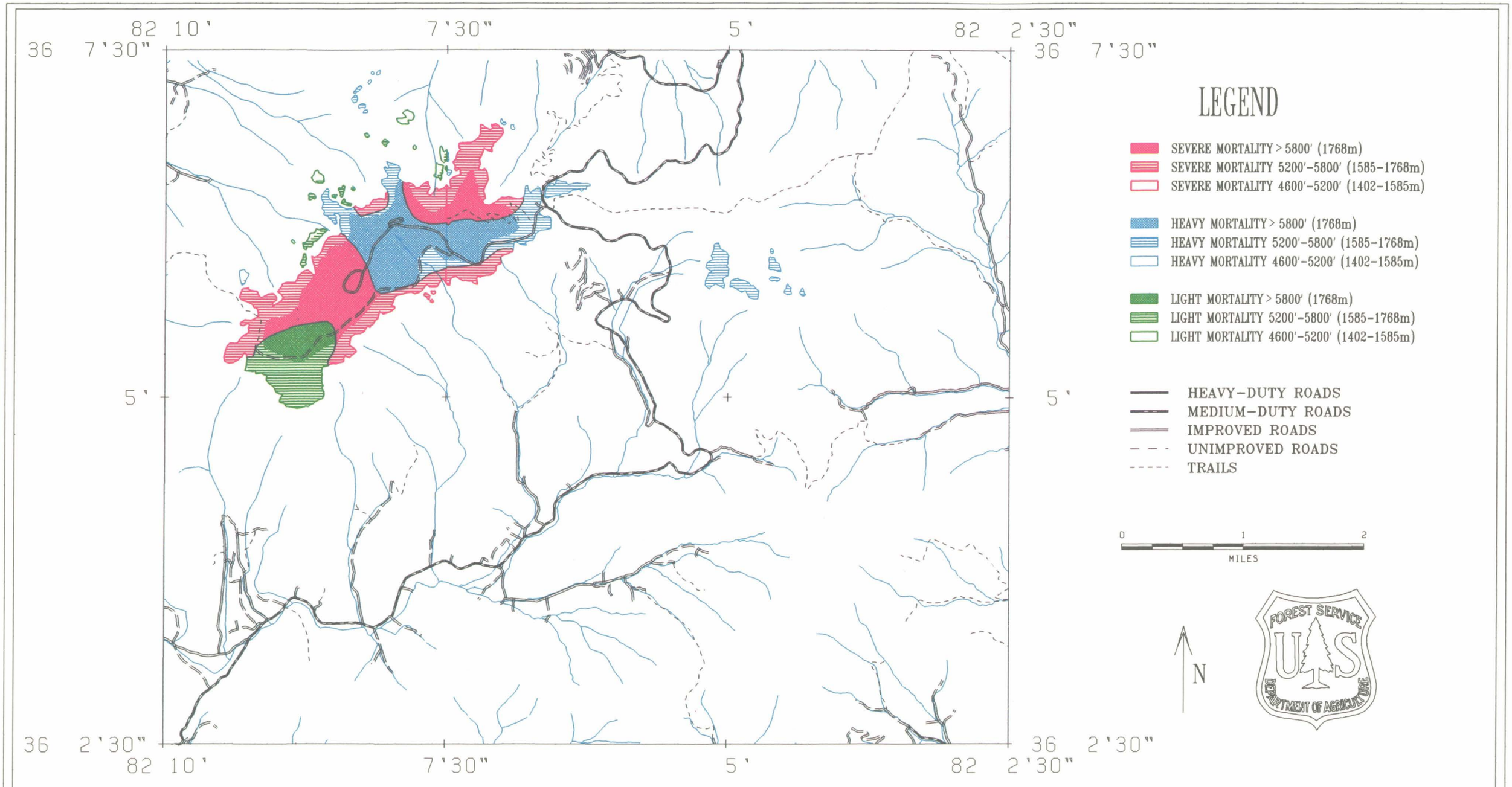


FIGURE 42- SPRUCE-FIR MORTALITY BY ELEVATION
ROAN MOUNTAIN

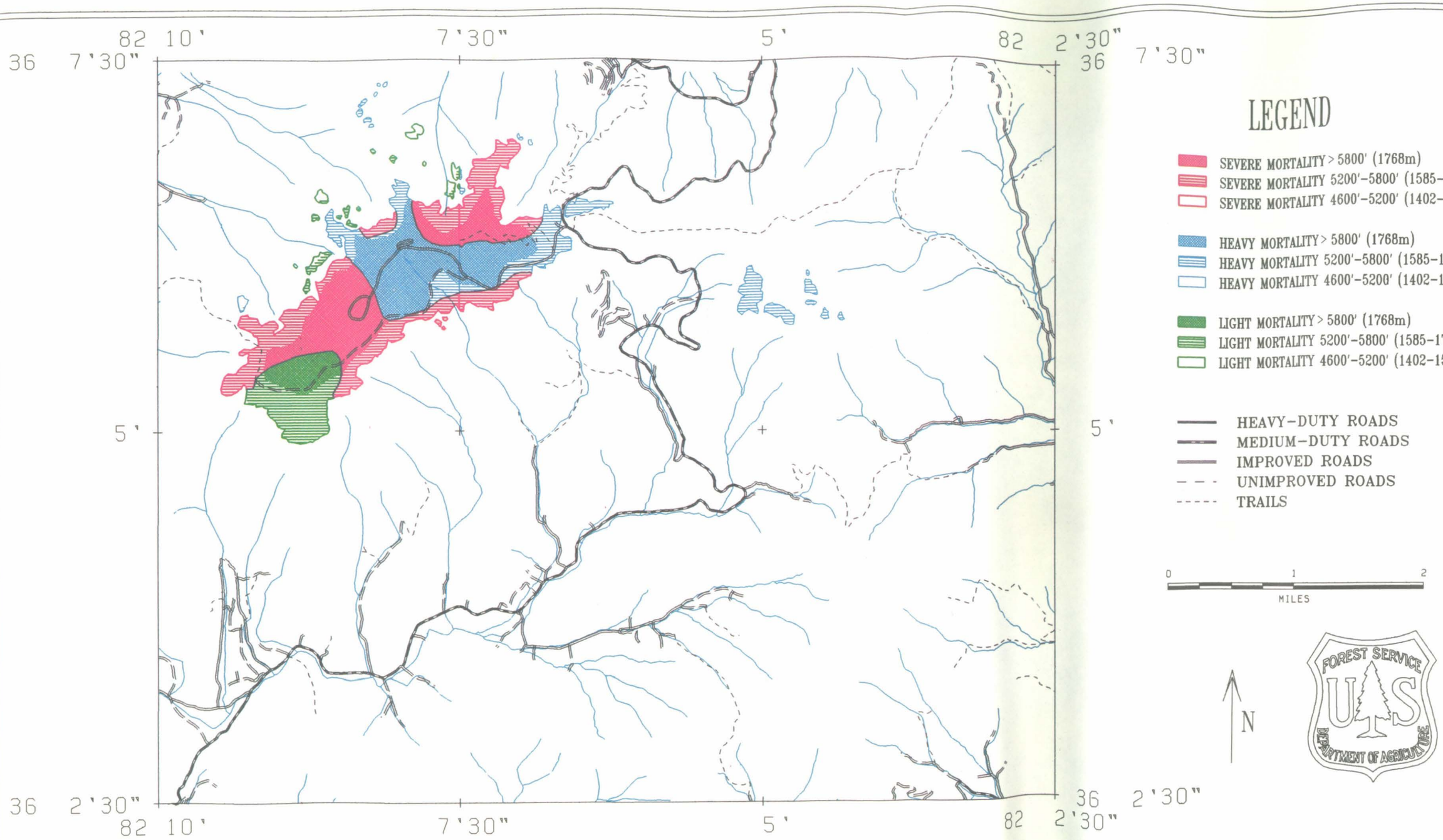


FIGURE 42- SPRUCE-FIR MORTALITY BY ELEVATION
ROAN MOUNTAIN

Volume Estimates

Total cubic foot volume per acre by condition and species are shown for each elevation stratum in table 10. Fir volume increases with elevation. Spruce volume per acre was variable between elevation strata, with the greatest volume per acre found at 5,400 to 6,000 feet (1,646 to 1,829 m) stratum (figure 46). Overall, 43% of Fraser fir

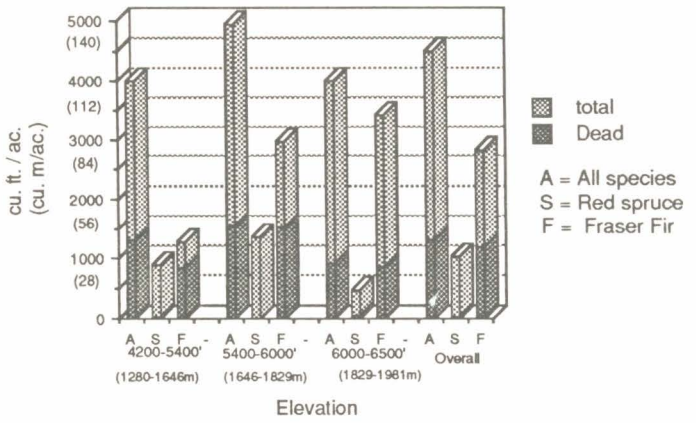


Figure 46.–Timber volume, by elevation, Roan Mountain.

volume was dead while less than 3% of the spruce volume was dead (figure 47). For all species for total volume by condition class, 30% was dead while 62% was healthy and 7% was declining (figure 48). Based on the results of this survey, total red spruce volume dead on Roan Mountain was 41,000 cubic feet (1,148 cubic meters). Fraser fir volume dead on Roan Mountain was 2.0 million cubic feet (56,000 cubic meters).

Balsam Woolly Adelgid History

In 1962, a local infestation of adelgids was detected on Roan mountain (Ciesla and Buchannan 1962). Entomologists estimated that the initial attack occurred sometime in 1960. In 1971, the Toecane Ranger District designated three areas for chemical control and treated one area each year. In 1971 on Roan Mountain's Rhododendron Garden Recreation Area, a generally light to moderate infestation was found over about 30 to 40 acres (12 to 16 ha) within the protection zone (Flavel and Lambert 1971). Widely scattered

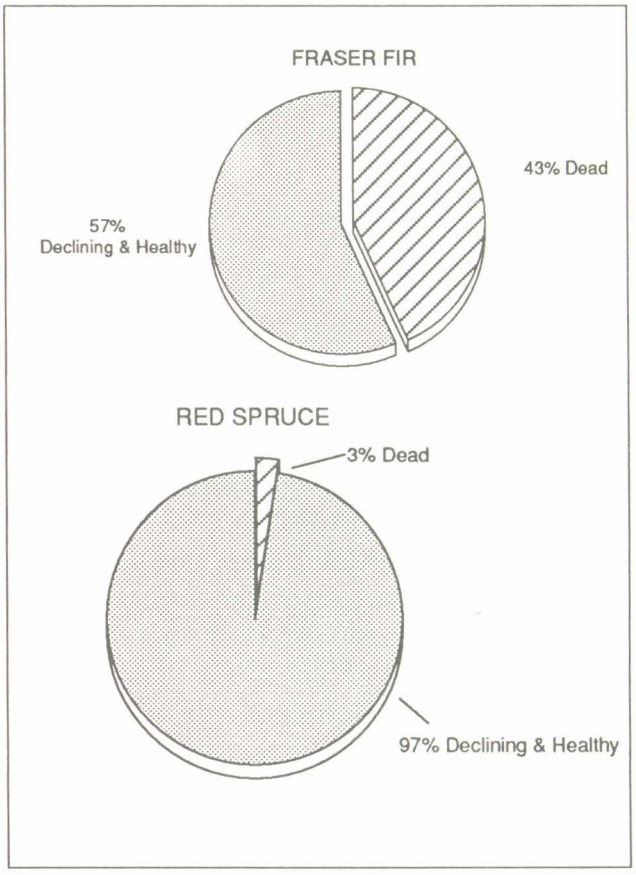


Figure 47. -Fraser fir and red spruce volume, by condition, on Roan Mountain.

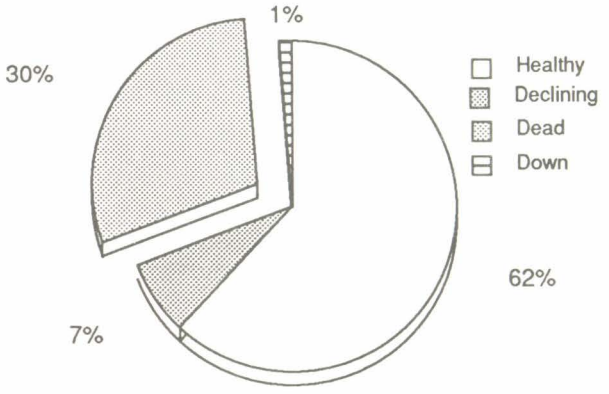


Figure 48.–Timber volume, by condition class, Roan Mountain.

mortality was predicted within the next 2 to 3 years, with heavy mortality in 3 to 4 years. By 1973 considerable tree mortality had occurred (Ward and others 1973) although the adelgid did not appear to be killing trees on Roan Mountain as

Table 10--Total ft^3 volume per acre by condition and species for elevation, Roan Mountain

	Elevation (ft)[m]											
	4200 - 5400 ft (1280 - 1646 m)			5400 - 6000 ft (1646 - 1829 m)			6000 - 6285 ft (1829 - 1916 m)			Overall		
Condition	S[1] (SE)	F[2] (SE)	All (SE)[3]	S(SE)	F(SE)	All (SE)	S(E)	F(SE)	All (SE)	S(SE)	F(SE)	All (SE)
Healthy ft	845 (198)	201 (31)	2296 (385)	1340 (131)	1019 (102)	2902 (237)	419 (109)	2206 (157)	2738 (212)	987 (84)	1238 (72)	2755 (156)
meter	24 (6)	6 (1)	64 (11)	38 (4)	29 (3)	81 (.7)	12 (3)	62 (4)	77 (6)	28 (2)	35 (2)	77 (4)
Declining ft	0 (0)	238 (77)	387 (211)	19 (0)	356 (40)	426 (89)	0 (0)	281 (45)	281 (45)	11 (0)	315 (28)	377 (60)
meter	0 (0)	7 (2)	11 (6)	.5 (0)	10 (1)	12 (3)	0 (0)	8 (1)	8 (1)	.3 (0)	9 (.7)	11 (2)
Dead ft	40 (0)	840 (69)	1300 (147)	10 (0)	1532 (66)	1557 (78)	53 (5)	856 (107)	909 (107)	27 (2)	1219 (49)	1324 (58)
meter	1 (0)	24 (2)	36 (4)	.3 (0)	43 (2)	44 (2)	2 (.1)	24 (3)	26 (3)	.7 (06)	34 (1)	37 (2)
Down ft	0 (0)	0 (0)	0 (0)	0 (0)	51 (10)	51 (10)	0 (0)	72 (18)	72 (18)	0 (0)	49 (8)	49 (8)
meter	0 (0)	0 (0)	0 (0)	0 (0)	1 (.3)	1 (.3)	0 (0)	2 (.5)	2 (.5)	0 (0)	1 (.2)	1 (.2)
All Conds.	885 (196)	1279 (111)	3983 (469)	1369 (131)	2958 (132)	4936 (274)	472 (108)	3415 (203)	4000 (249)	1025 (84)	2821 (95)	4505 (182)
meter	25 (6)	36 (3)	112 (13)	38 (4)	83 (4)	138 (8)	13 (3)	96 (6)	112 (7)	29 (2)	79 (3)	126 (5)

[1] S = Red spruce
[2] F = Fraser fir
[3] SE = Standard Error

fast it did on Mount Mitchell or the Great Smoky Mountains National Park. The extent and severity of the infestations increased in 1974 (Ward 1974). Ground evaluations revealed large numbers of new infestations and an increase in the spread of previously known infestations. Heavy tree mortality was predicted to occur in 1975 or 1976. Large increases in the spread and mortality of Fraser fir were again noted in 1977.

Results of a 1979 survey indicated that the chemical control procedures were effective (Barry and Oprean 1979). In 1981, a survey indicated there was a definite need for the spray program to be changed from every 3 years to every 2 years for each of the protection areas. Several surveys indicated that protection boundaries were essential for protecting seed collection areas for Fraser fir (Barry 1981).

Locations of balsam woolly adelgid activity compiled from eight evaluations conducted by Forest Pest Management from 1965 through 1978 were digitized. Acreages by year varied significantly, ranging from 89 to 518 acres (36 to 210 ha) infested. The protection zone occupied a total of 589 acres (238 ha) over the period of years for which suppression activities were conducted.

Study Plot Locations

Figure 49 illustrates the location of Forest Pest Management's study plots located on Roan Mountain.

The Balsam Mountains

The area of spruce and fir along the Blue Ridge Parkway south of Asheville, NC and extending to the west and southwest of Waynesboro, is also commonly called the Balsam Mountains and the Plott Balsams. Spruce-fir forests are located in Pisgah and Nantahala National Forests in Haywood, Transylvania, and Jackson counties, North Carolina. The highest peak in the area, Mount Pisgah, reaches an elevation of 6,410 feet (1,954 m). The National Park Service has administrative responsibility for all the Blue Ridge Parkway in the central portion of the Pisgah Ranger District, which turns to the northwest at Beech Gap and continues to the west of Waynesville. This is a popular scenic highway and also provides access to the Cradle of Forestry in America.

Spruce-fir Area and Mortality Class

The spruce-fir type occupies a relatively narrow elevational band covering 5,601 acres (2,267 ha) along the Blue Ridge Parkway (figure 50). Severe mortality was classified on 53% of the total area with heavy mortality at 10% of the area, and 37% of the area classified as light (figure 51). A greater percentage of severe mortality in relation to total type area, was found in the Balsam Mountains than for any of the other five geographic areas. Only 8% of the total spruce-fir type was found below 5,200 feet (1,585 m) (figure 52). Again, severe mortality occupied a majority of the higher elevation stratum with light mortality found at the lower elevations. Only 22 acres (9 ha) of spruce and fir type occurred above 5,800 feet (1,768 m) with 445 acres (180 ha) found below 5,200 feet (1,585 m). The sample size was inadequate at the lower and upper elevation strata because of the narrow elevational bands of type. Overall, 84% mortality was found in Fraser fir with 5% mortality for red spruce (figure 53). The percentage of Fraser fir in the stand component ranged from 24% at lower elevations to 42% at mid-elevations and showed a decrease in the upper elevations (figure 54). These data may be misleading due to the insufficient sample size, again at the lower and upper elevations.

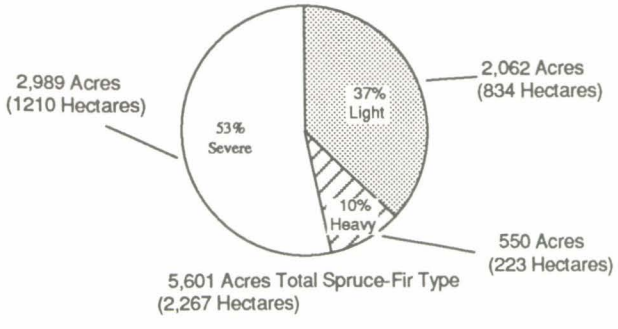


Figure 51.–Spruce-fir type (acres) on the Balsam Mountains, classified by mortality.

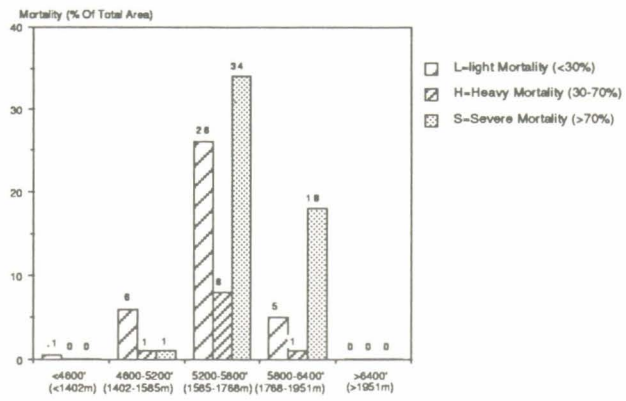


Figure 52.–Spruce-fir mortality (acres) stratified by elevation on the Balsam Mountains.

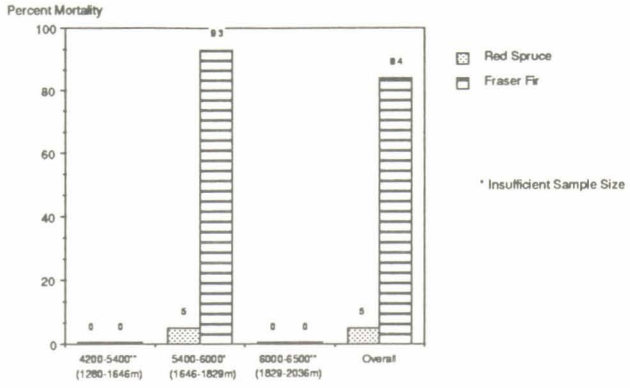


Figure 53.–Spruce-fir mortality (percent) by elevation on the Balsam Mountains.

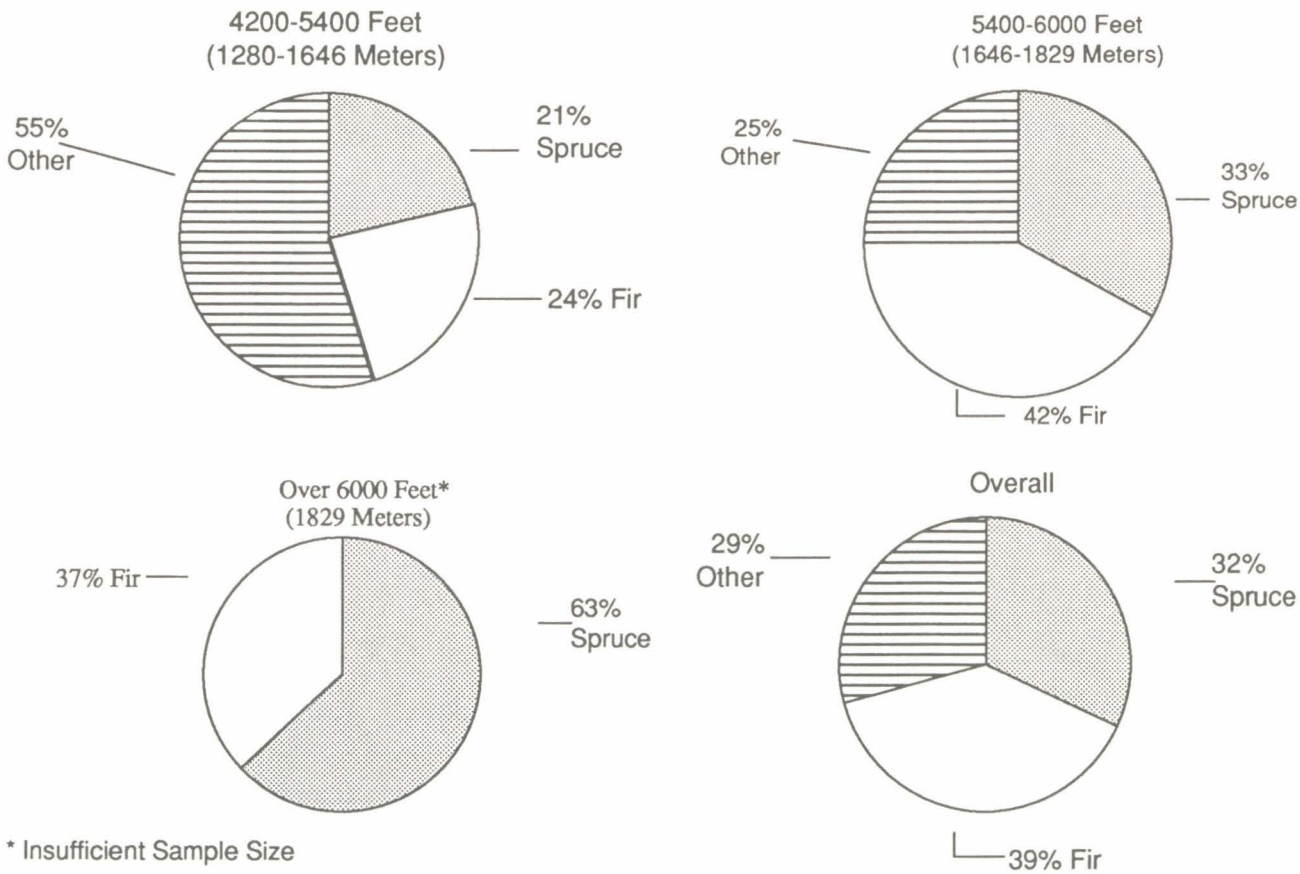


Figure 54.—Spruce-fir stand component classified by elevation for the Balsam Mountains.

82 10' 7'30" 5' 82 2'30"

36 7'30"

36 7'30"

5'

5'

36 2'30"

36 2'30"

82 10' 7'30" 5' 82 2'30"

LEGEND

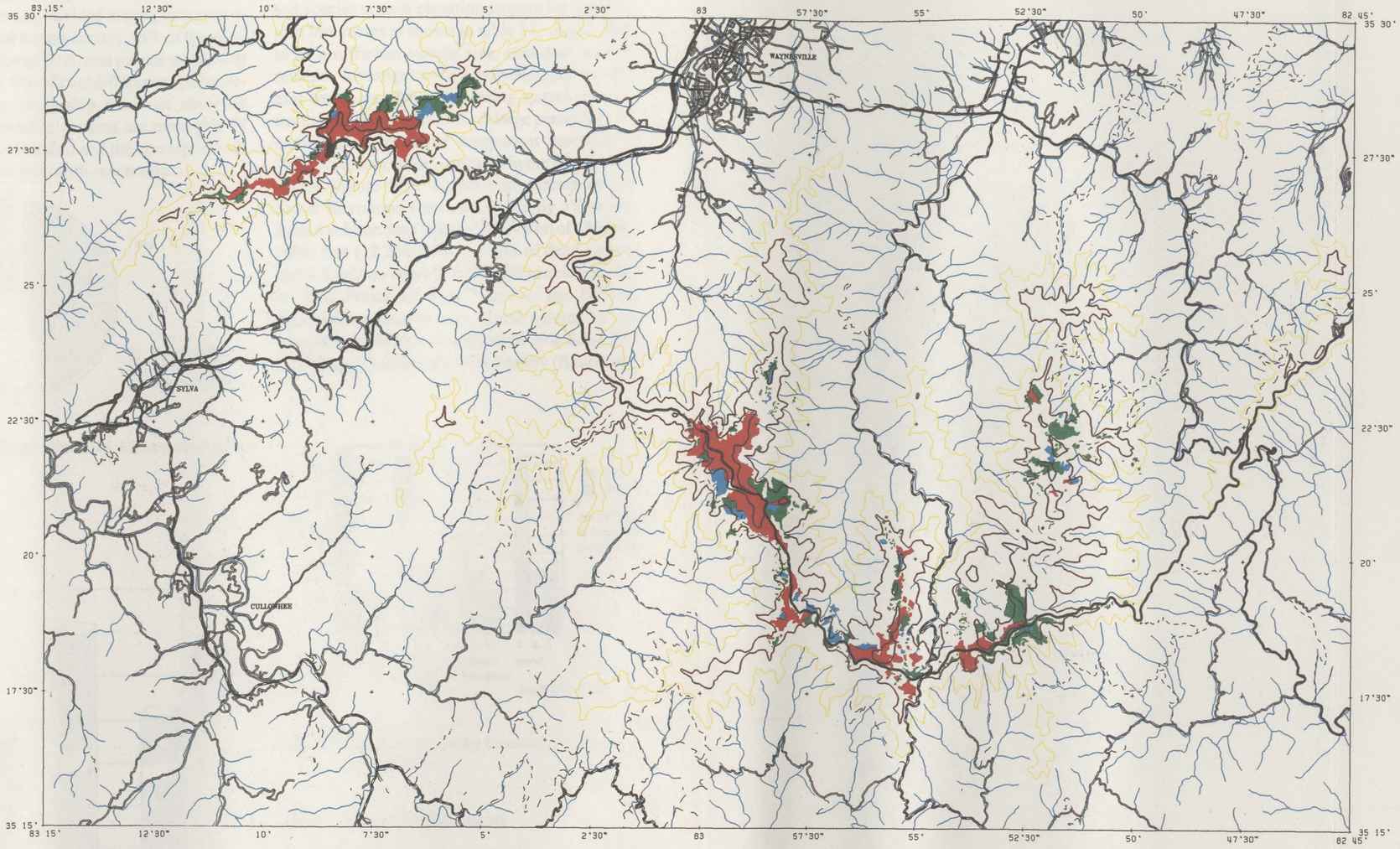
- FOREST SERVICE GROUND PLOTS
- FOREST SERVICE PHOTO PLOTS
- SPRUCE-FIR TYPE

- HEAVY-DUTY ROADS
- MEDIUM-DUTY ROADS
- IMPROVED ROADS
- UNIMPROVED ROADS
- TRAILS

N

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

FIGURE 49- STUDY PLOT LOCATIONS, ROAN MOUNTAIN



LEGEND

	PERCENT	ACRES	HECTARES
SEVERE MORTALITY (>70%)	53	2989	834
HEAVY TO MODERATE MORTALITY (30-70%)	10	550	223
LIGHT MORTALITY (<30%)	37	2062	1210
TOTAL SPRUCE-FIR FOREST TYPE AREA		5601	2267

HEAVY-DUTY ROADS
MEDIUM-DUTY ROADS
IMPROVED ROADS
UNIMPROVED ROADS
TRAILS

6400 FOOT (1951 METER) CONTOUR LINE
5800 FOOT (1768 METER) CONTOUR LINE
5200 FOOT (1585 METER) CONTOUR LINE
4600 FOOT (1402 METER) CONTOUR LINE

STREAMS AND RIVERS

N

FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE

0 1 2 3 4
MILES

FIGURE 50- SPRUCE-FIR MORTALITY, BALSAM MOUNTAINS, N.C.

Ownership Patterns in Relation to Spruce-fir Distribution

Spruce-fir type along the Balsam Mountains was relatively evenly divided among major ownerships. National forests occupy 46% of the type, Blue Ridge Parkway 29%, and private ownership 25% (figure 55). Significant differences in spruce-fir mortality by ownership were not observed (figure 56). Mortality patterns are more closely associated with elevation and the corresponding stand component than with ownership.

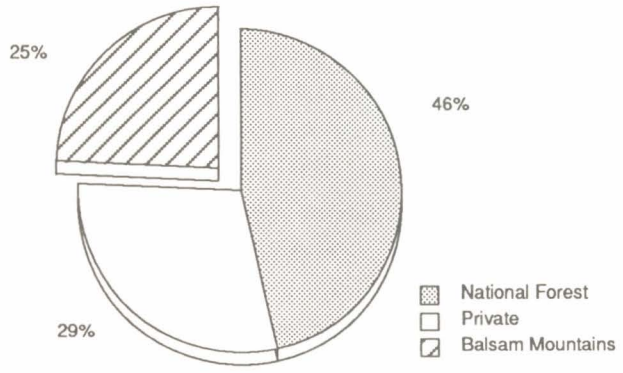


Figure 55.–Spruce-fir ownership, Balsam Mountains.

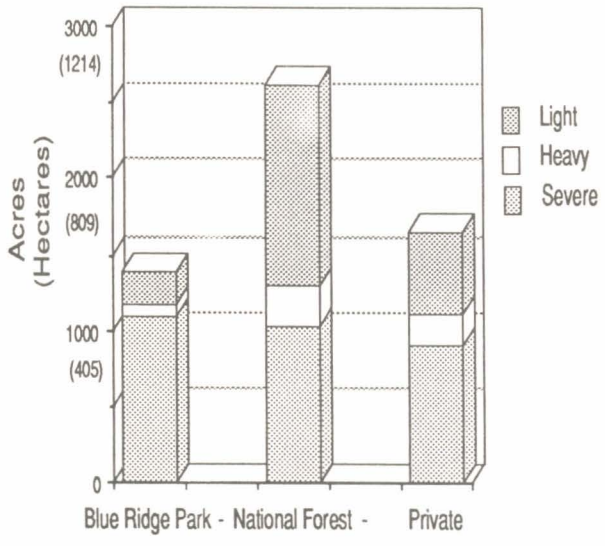


Figure 56.–Spruce-fir mortality, by ownership, Balsam Mountains.

Volume Estimates for Spruce-fir Type of the Balsam Mountains

Total cubic foot volume per acre by condition and species at each elevation stratum for the Balsam Mountains is shown in table 11. Again, due to an insufficient sample size, estimates are not reliable. Investigators feel, however, that fir volume increases with a decreasing spruce component as elevation increases. A large percentage of hardwood in the stand component produced a large cubic foot volume per acre in the Blue Ridge region (figure 57). Eighty-four percent of the Fraser fir volume was dead, with only 5% of red spruce volume dead (figure 58). A total of 436,000 cubic feet (12,208 cubic meters) of dead spruce and 8.5 million cubic feet (238,000 cubic meters) of dead Fraser fir were found in the Balsam Mountains spruce-fir type. Total volume for all species by condition class showed 39% dead, 3% declining, 1% down and 57% healthy (figure 59).

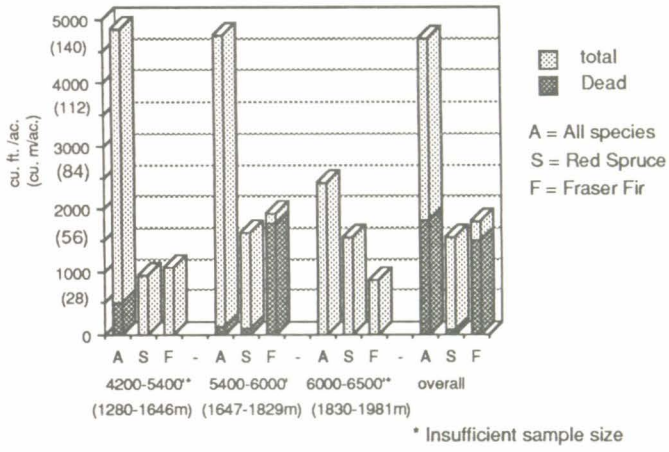


Figure 57.–Timber volume by elevation, Balsam Mountains.

Balsam Woolly Adelgid History

In the Balsam Mountains, aerial surveys conducted in 1966 revealed a number of dying Fraser fir, but subsequent ground checks failed to reveal the presence of balsam woolly adelgid (Lambert and Ciesla 1967). In 1968 the adelgid was de-

Table 11--Total ft[3] volume per acre by condition and species for elevation, Balsam Mountains, NC

Condition	Elevation (ft)[m]											
	4200 - 5400 ft[1] [1280 - 1646 m]			5400 - 6000 ft [1646 - 1829 m]			6000 - 6500 ft[1] [1829 - 2036 m]			Overall		
	S[2] (SE)	F[3] (SE)	All (SE)[4]	S(SE)	F(SE)	All (SE)	S(E)	F(SE)	All (SE)	S(SE)	F(SE)	All (SE)
Healthy-ft	930 (221)	1068 (176)	4182 (895)	1531 (221)	76 (12)	2485 (276)	1550 (642)	336 (0)	1887 (760)	1453 (189)	212 (25)	2691 (261)
meter	26 (6)	30 (5)	117 (25)	43 (6)	2 (.3)	70 (8)	43 (18)	9 (0)	53 (21)	41 (5)	6 (.7)	75 (7)
Declining-ft	0 (0)	0 (0)	167 (4)	12 (1)	36 (6)	127 (25)	0 (0)	531 (260)	531 (260)	10 (1)	45 (8)	143 (22)
meter	0 (0)	0 (0)	5 (.1)	.3 (.03)	1 (.2)	4 (.7)	0 (0)	15 (7)	15 (7)	.3 (.03)	1 (.2)	4 (.6)
Dead-ft	0 (0)	0 (0)	501 (152)	92 (11)	1789 (117)	2089 (134)	0 (0)	0 (0)	0 (0)	78 (9)	1509 (99)	1827 (114)
meter	0 (0)	0 (0)	14 (4)	3 (.3)	50 (3)	58 (4)	0 (0)	0 (0)	0 (0)	2 (.3)	42 (3)	51 (3)
Down-ft	0 (0)	0 (0)	0 (0)	0 (0)	32 (19)	44 (24)	0 (0)	0 (0)	0 (0)	0 (0)	27 (16)	37 (20)
meter	0 (0)	0 (0)	0 (0)	0 (0)	.9 (.5)	1 (.7)	0 (0)	0 (0)	0 (0)	0 (0)	.8 (.4)	1 (.6)
All Conds.	930 (221)	1068 (176)	4850 (1005)	1635 (225)	1933 (126)	4745 (306)	1550 (642)	867 (317)	2418 (806)	1541 (193)	1793 (109)	4698 (290)
meter	26 (6)	30 (5)	136 (28)	46 (6)	54 (4)	133 (9)	43 (18)	24 (9)	68 (23)	43 (5)	50 (3)	131 (8)

[1] Insufficient sample size with low acreage at these stratum

[2] S = Red spruce

[3] F = Fraser fir

[4] SE = Standard Error

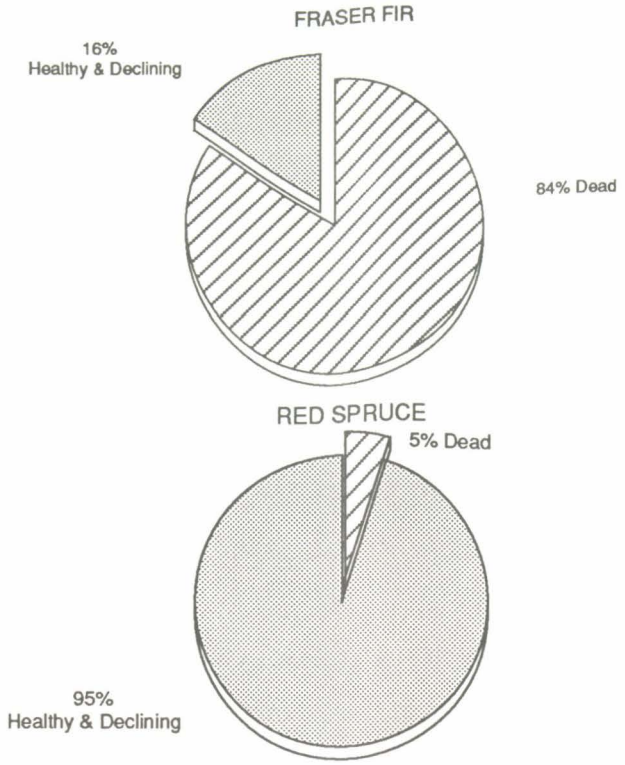


Figure 58.–Fraser fir and red spruce volume, by condition, on the Balsam Mountains.

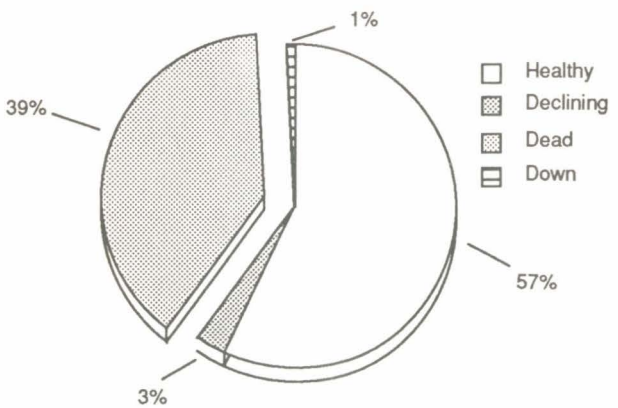


Figure 59 –Timber volume by condition class, Balsam Mountains.

tected in a remote area of the Balsam Mountains for the first time (Rauschensberger and Lambert 1969). All infestations contained green or newly infested trees; no mortality was observed in or near any of the spots. By 1970 spot infestations had grown to encompass approximately 25 acres (10 ha) (Rauschensberger and Lambert 1970). A light to moderate infestation was subsequently detected along the Blue Ridge Parkway (Flavell and Lambert 1971). At that time, extensive fir mortality was predicted to occur. Since that time extensive mortality as a result of balsam woolly adelgid infestations has become a reality. Spruce-fir type along the Blue Ridge Parkway was one of the last areas in the southeast to become infested.

Study Plot Locations

The locations of Forest Pest Management photo plots and ground plots along the Blue Ridge Parkway are shown in figure 60.

Grandfather Mountain

Grandfather Mountain rises to an elevation of 5,964 feet (1,818 m). Spruce-fir type in this area is in Watauga, Avery, and Caldwell Counties in North Carolina.

Spruce-fir Area and Mortality Classification

Spruce-fir type covered 928 acres (376 ha) (figure 61). Within the type 16% was classified as severe mortality, 13% heavy, and 71% light (figure 62).

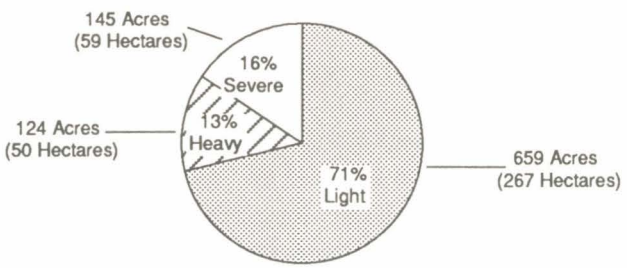


Figure 62.–Spruce-fir type (acres) on Grandfather Mountain, classified by mortality.

Spruce and Fir Mortality Classification

The percentage of the area classified as severe mortality increased with increasing elevation (figure 63), as determined by overlaying topology

and mortality classification in the GIS. Only 20 acres (8 ha) occupied the areas above 5,800 feet (1,768 m) of which 50% was classified as severe. Twenty-three percent of the area between 5,200 to 5,800 feet (1,585 to 1,768 m) was classified as severe, and occupied 14% of the total spruce-fir area on Grandfather Mountain (figure 64).

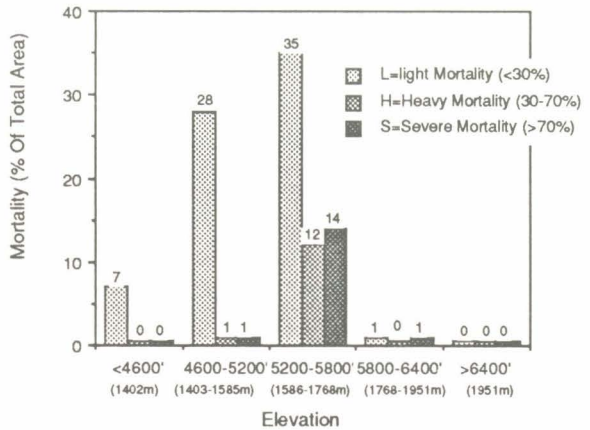


Figure 63.–Spruce-fir mortality (acres), stratified by elevation, on Grandfather Mountain.

Ownership Patterns on Grandfather Mountain

Ninety-eight percent of the spruce-fir type on Grandfather Mountain is in private ownership. Only a very small percentage occurs on the Blue Ridge Parkway and national forests.

Balsam Woolly Adelgid History

Balsam woolly adelgid was first detected on Grandfather Mountain in 1963. Aerial and ground surveys revealed a heavy infestation (Lambert and Franklin 1963). The locations of balsam woolly adelgid infestations as reported in Forest Pest Management biological evaluations were digitized by the GIS to determine infested acreages that ranged from 70 acres (28 ha) in 1963 to a maximum of 536 acres (217 ha) in 1966, declining to 390 acres (157 ha) in 1969. At present, the entire spruce-fir type on Grandfather Mountain is considered to be infested.

Mount Rogers and White Top Mountain

The summit of Mount Rogers is the highest point in Virginia, reaching an elevation of 5,729 feet (1,746 m). The Mount Rogers area is the northernmost extent of the spruce-fir type in the southern Appalachians and the northern limit of the natural range of Fraser fir. It is located in the Jefferson National Forest and designated as a national recreation area in Smyth and Grayson Counties. White Top Mountain, at an elevation of 5,650 feet (1,722 m), is also located in the Jefferson National Forest in Smyth, Grayson, and Washington Counties.

Spruce-fir Area and Mortality Classification

The spruce-fir type on Mount Rogers and White Top Mountain occupies 1,582 acres (640 ha) (figure 65). All of the spruce-fir type was classified in the light mortality class.

Spruce and Fir Mortality in Relation to Elevation

Although all the type was classified as light mortality, the percentage and location of the type in relation to elevation was evaluated. Only 2% of the type was below 4,600 feet (1,402 m), 54% between 4,600 to 5,200 feet (1,402 to 1,585 m) and 44% was found between 5,200 and 5,800 feet (1,585 and 1,768 m) (figure 66). Previous surveys

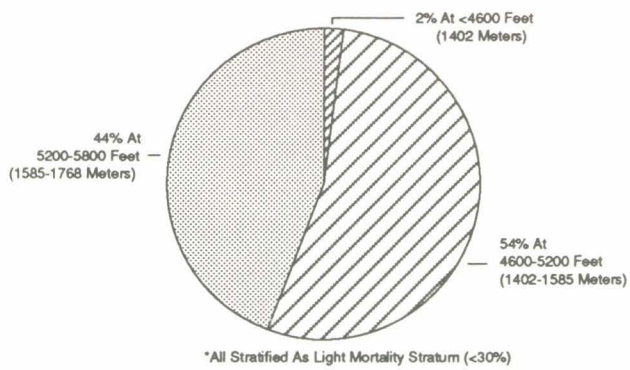

2% At <4600 Feet (1402 Meters)
44% At 5200-5800 Feet (1585-1768 Meters)
54% At 4600-5200 Feet (1402-1585 Meters)
*All Stratified As Light Mortality Stratum (<30%)

Figure 66.–Spruce-fir forest type (acres), stratified by elevation, on Mount Rogers and White Top Mountains.

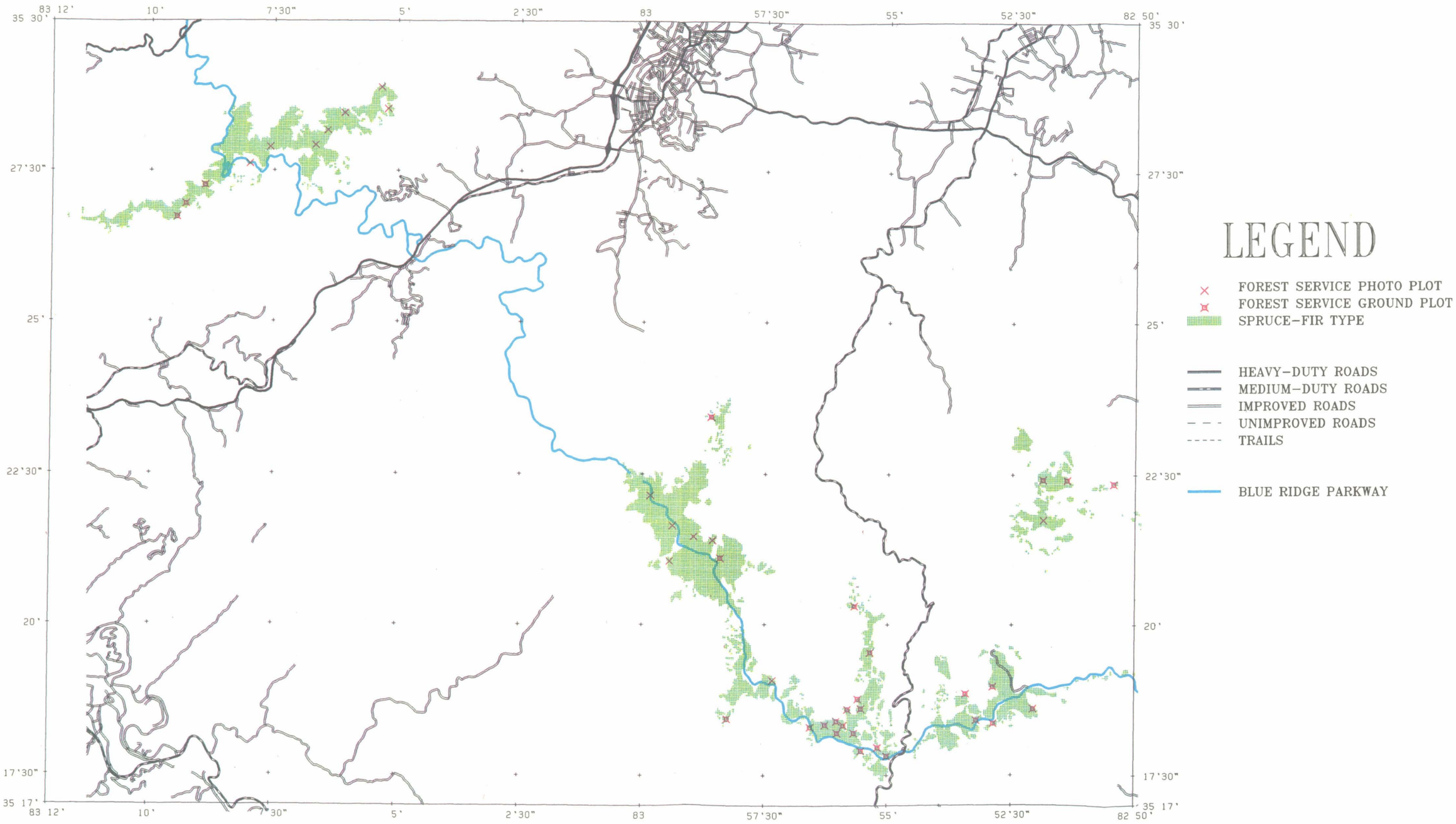


FIGURE 60 – STUDY PLOT LOCATIONS, BALSAM MOUNTAINS

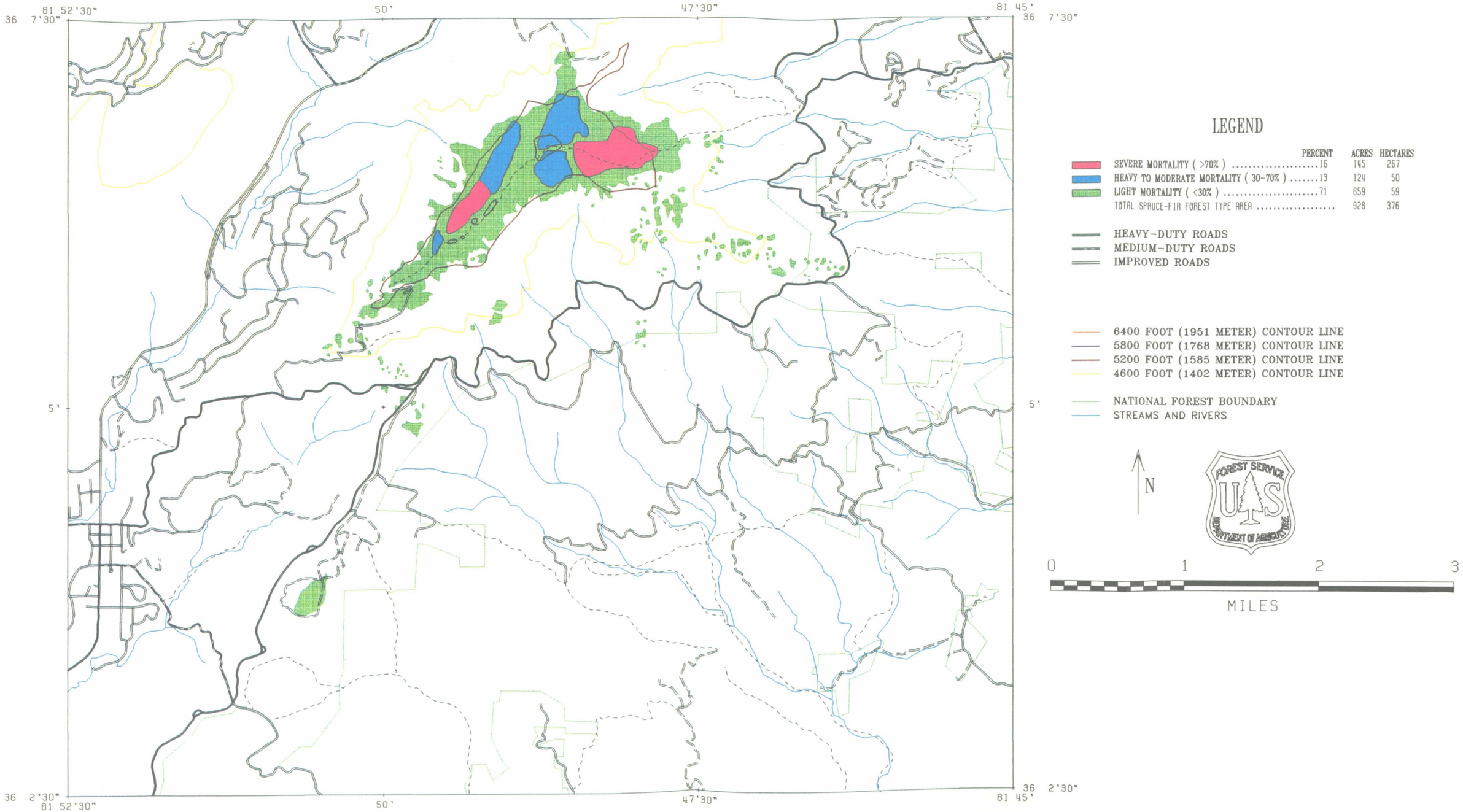
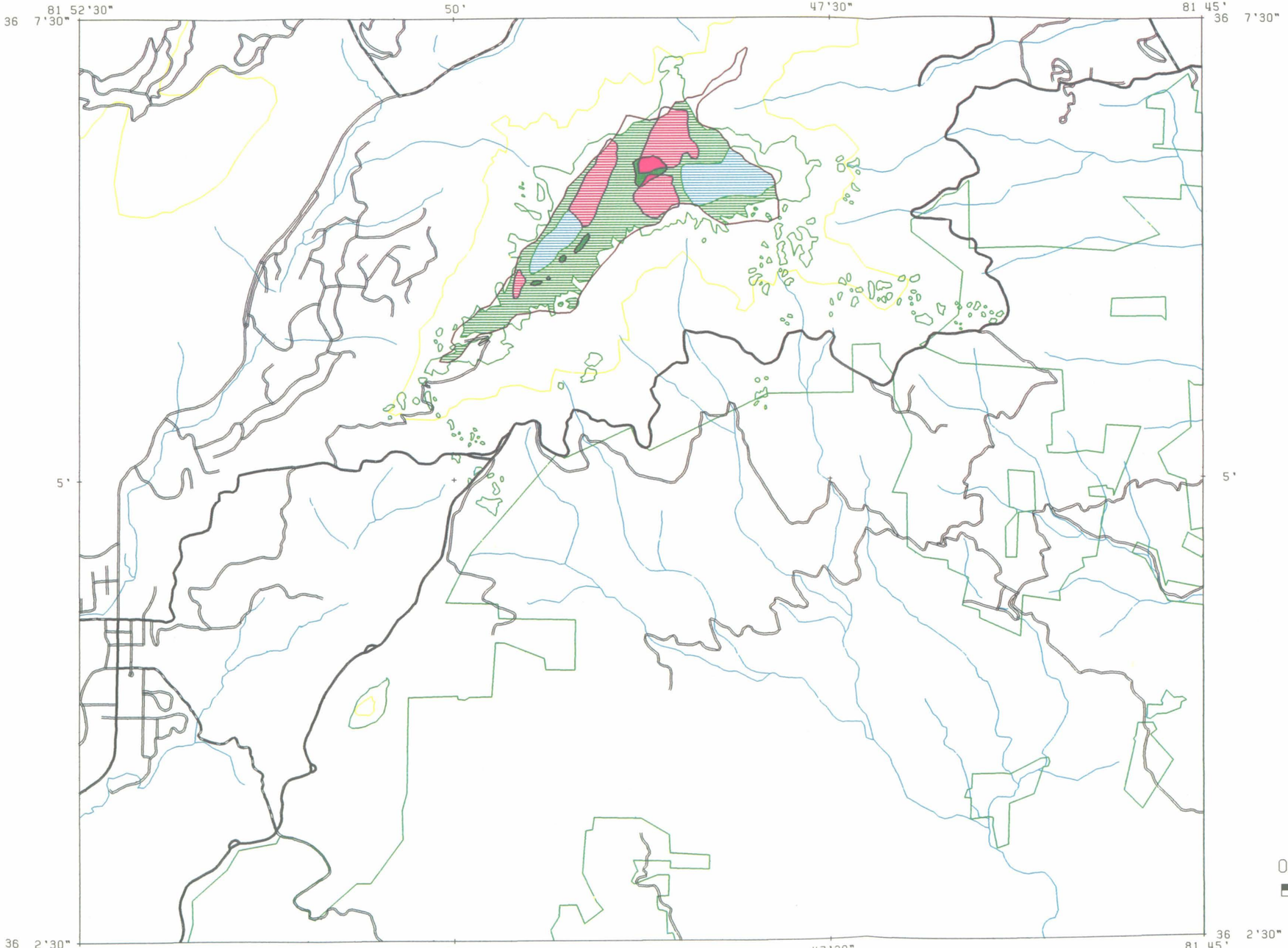


FIGURE 61- SPRUCE-FIR MORTALITY, GRANDFATHER MT., NC.



LEGEND

- SEVERE MORTALITY > 5800' (1768m)
- SEVERE MORTALITY 5200'–5800' (1585–1768m)
- SEVERE MORTALITY 4600'–5200' (1402–1585m)
- HEAVY MORTALITY > 5800' (1768m)
- HEAVY MORTALITY 5200'–5800' (1585–1768m)
- HEAVY MORTALITY 4600'–5200' (1402–1585m)
- LIGHT MORTALITY > 5800' (1768m)
- LIGHT MORTALITY 5200'–5800' (1585–1768m)
- LIGHT MORTALITY 4600'–5200' (1402–1585m)
- HEAVY–DUTY ROADS
- MEDIUM–DUTY ROADS
- IMPROVED ROADS
- 6400 FOOT (1951 METER) CONTOUR LINE
- 5800 FOOT (1768 METER) CONTOUR LINE
- 5200 FOOT (1585 METER) CONTOUR LINE
- 4600 FOOT (1402 METER) CONTOUR LINE
- NATIONAL FOREST BOUNDARY
- STREAMS AND RIVERS

N

FOREST SERVICE U S DEPARTMENT OF AGRICULTURE

0 1 2 3

MILES

FIGURE 64 – MORTALITY BY ELEVATION, GRANDFATHER MOUNTAIN

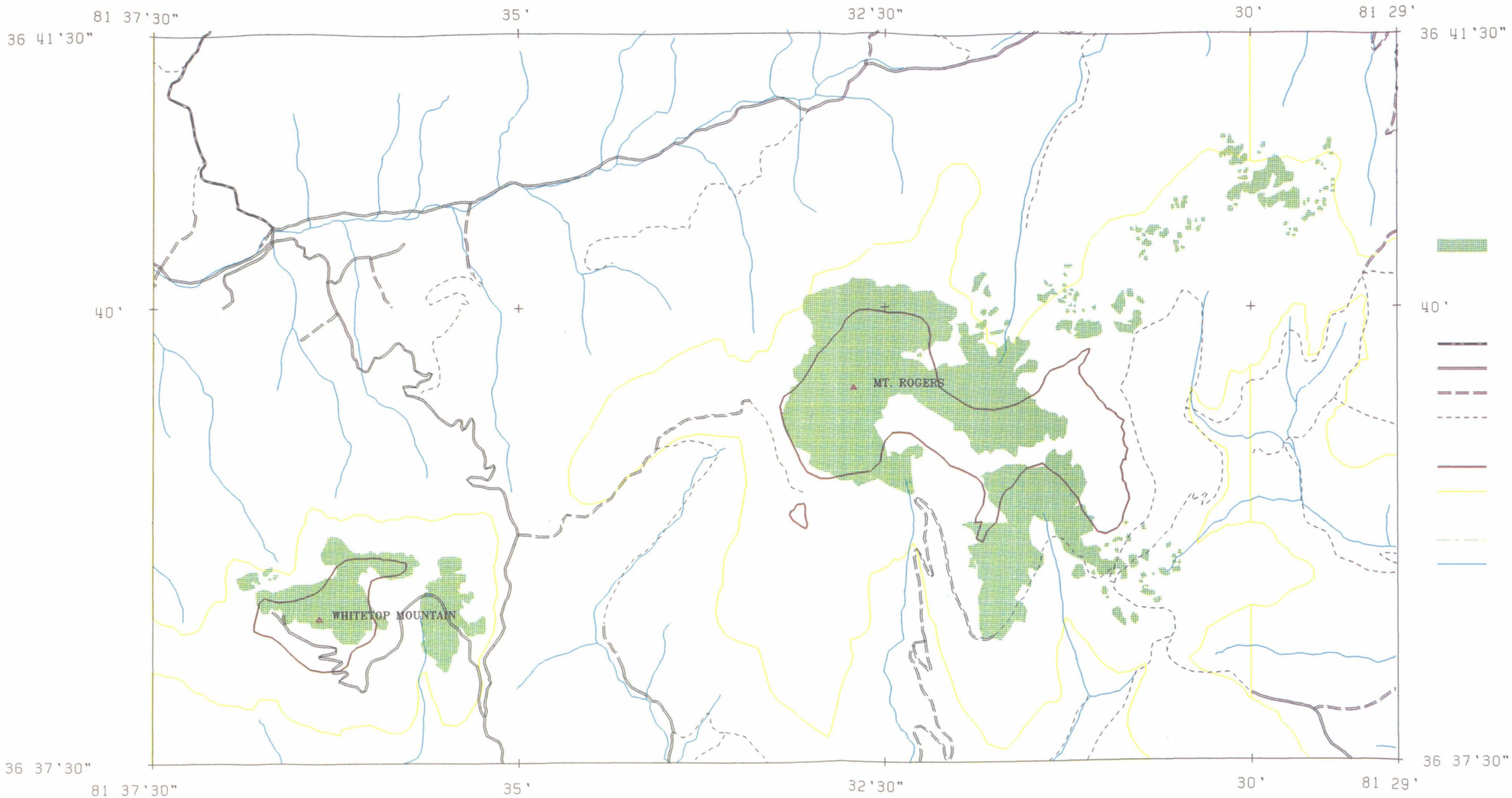
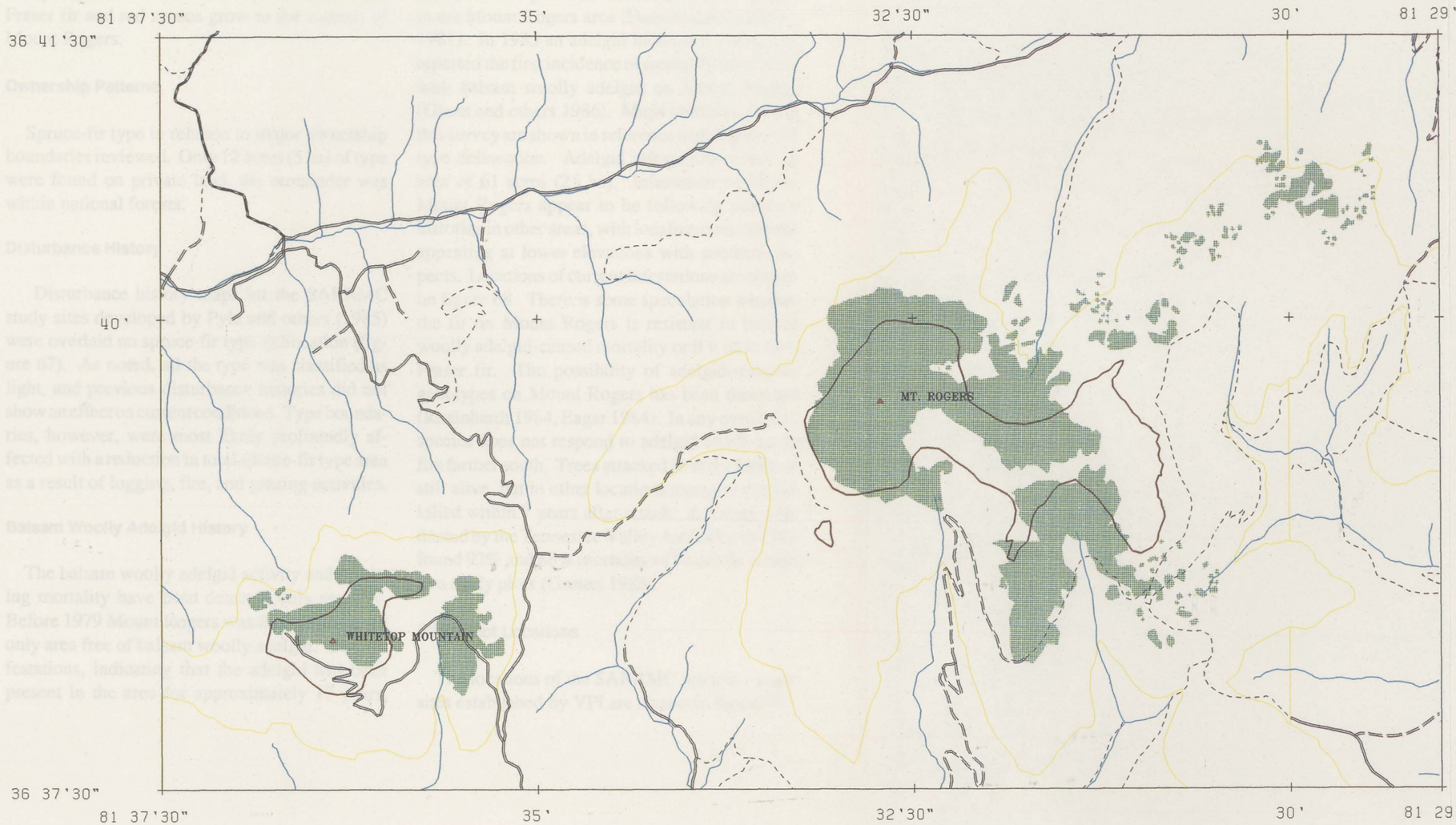


FIGURE 65- SPRUCE-FIR MORTALITY
MT.ROGERS & WHITE TOP MT., VA.



LEGEND

- SPRUCE-FIR TYPE TOTAL AREA = 1582 ACRES, 640.2 HECTARES
  ENTIRE SPRUCE-FIR TYPE ON MT. ROGERS AND WHITETOP MTN.
  INTERPRETED AS LOW MORTALITY (LESS THAN 30%)
- MEDIUM-DUTY ROADS
- IMPROVED ROADS
- UNIMPROVED ROADS
- TRAILS
- 5200 FOOT (1585 METER)CONTOUR LINE
- 4600 FOOT (1402 METER) CONTOUR LINE
- NATIONAL FOREST BOUNDRY
- STREAMS

FIGURE 65- SPRUCE-FIR MORTALITY
MT.ROGERS & WHITE TOP MT., VA.

showed a typical pattern of mixed spruce and fir shifting to nearly pure stands of fir with increasing elevation (Stephenson and Adams 1984). Only red spruce is found on White Top Mountain while Fraser fir and red spruce grow to the summit of Mount Rogers.

Ownership Patterns

Spruce-fir type in relation to major ownership boundaries reviewed. Only 12 acres (5 ha) of type were found on private land, the remainder was within national forests.

Disturbance History

Disturbance history maps for the SARRMC study sites developed by Pyle and others (1985) were overlaid on spruce-fir type delineation (figure 67). As noted, all the type was classified as light, and previous disturbance histories did not show an effect on current conditions. Type boundaries, however, were most likely profoundly affected with a reduction in total spruce-fir type area as a result of logging, fire, and grazing activities.

Balsam Woolly Adelgid History

The balsam woolly adelgid activity and resulting mortality have been detected only recently. Before 1979 Mount Rogers was thought to be the only area free of balsam woolly adelgid. Two infestations, indicating that the adelgid had been present in the area for approximately 17 years, were discovered during Forest Pest Management's survey and evaluation conducted in 1979 (Lambert and others 1980). Surveys conducted in 1980 reaffirmed the presence of balsam woolly adelgid in the Mount Rogers area (Haneman and others 1981). In 1985 an adelgid biological evaluation reported the first incidence of mortality associated with balsam woolly adelgid on Mount Rogers (Ghent and others 1986). Maps produced during this survey are shown in reference to the spruce-fir type delineation. Adelgid infestations cover an area of 61 acres (25 ha). Infestation trends on Mount Rogers appear to be following previous histories in other areas, with localized infestations appearing at lower elevations with southern aspects. Locations of current infestations are shown on figure 68. There is some speculation whether the fir on Mount Rogers is resistant to balsam woolly adelgid-caused mortality or if it is, in fact, Fraser fir. The possibility of adelgid-resistant genotypes on Mount Rogers has been theorized (Rheinhardt 1984, Eagar 1984). In any event, this species does not respond to adelgid attack as do firs farther south. Trees attacked in early 1960 are still alive, but in other locations trees are usually killed within 7 years after attack. A survey conducted by the Tennessee Valley Authority in 1985 found 92% and 88% mortality of Fraser fir within two study plots (Groton 1985).

Study Plot Locations

The locations of the SARRMC intensive study sites established by VPI are shown in figure 69.

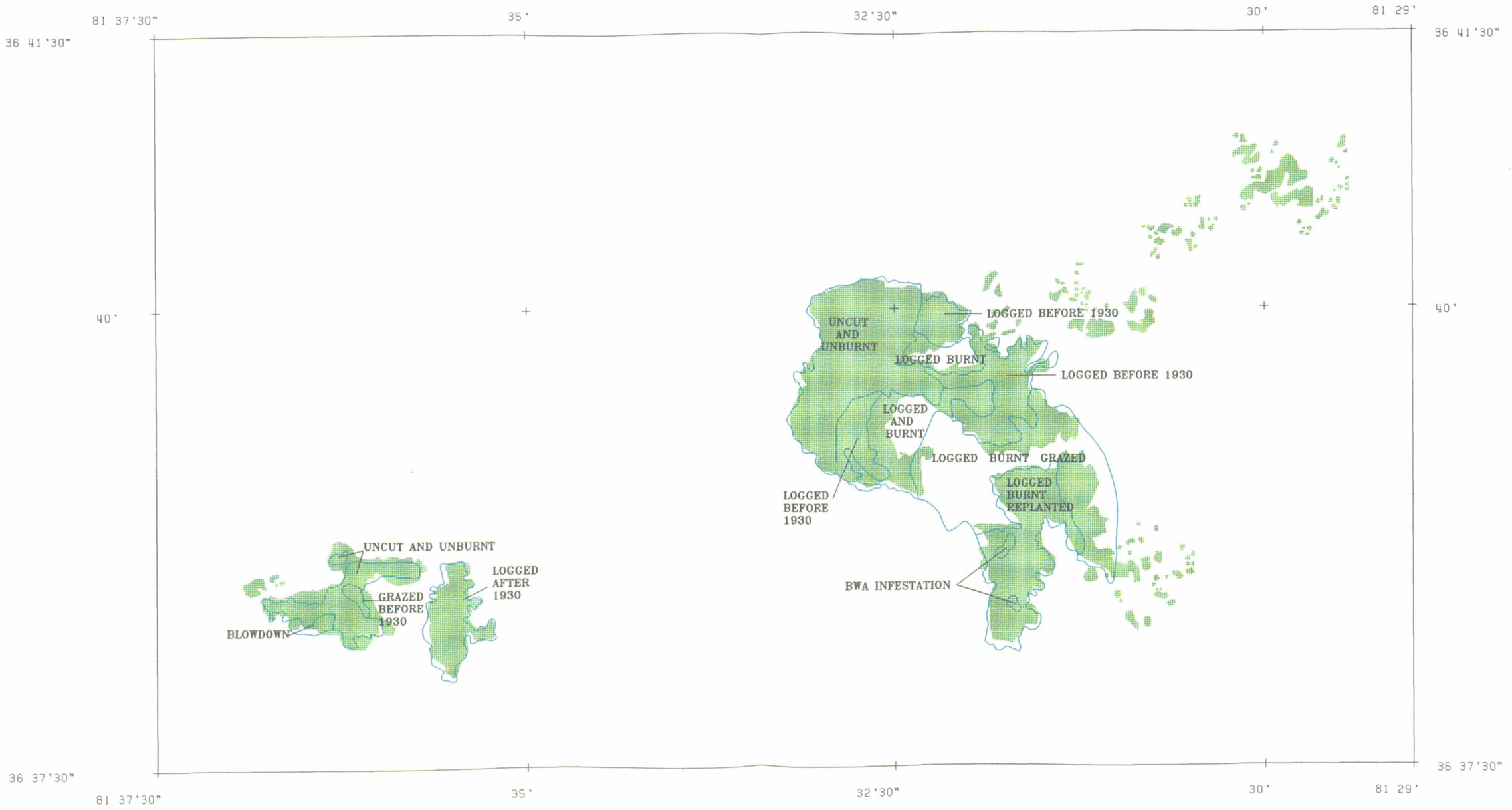


FIGURE 67 – SPRUCE–FIR DISTURBANCE HISTORY, MT.ROGERS AND WHITETOP MTN.

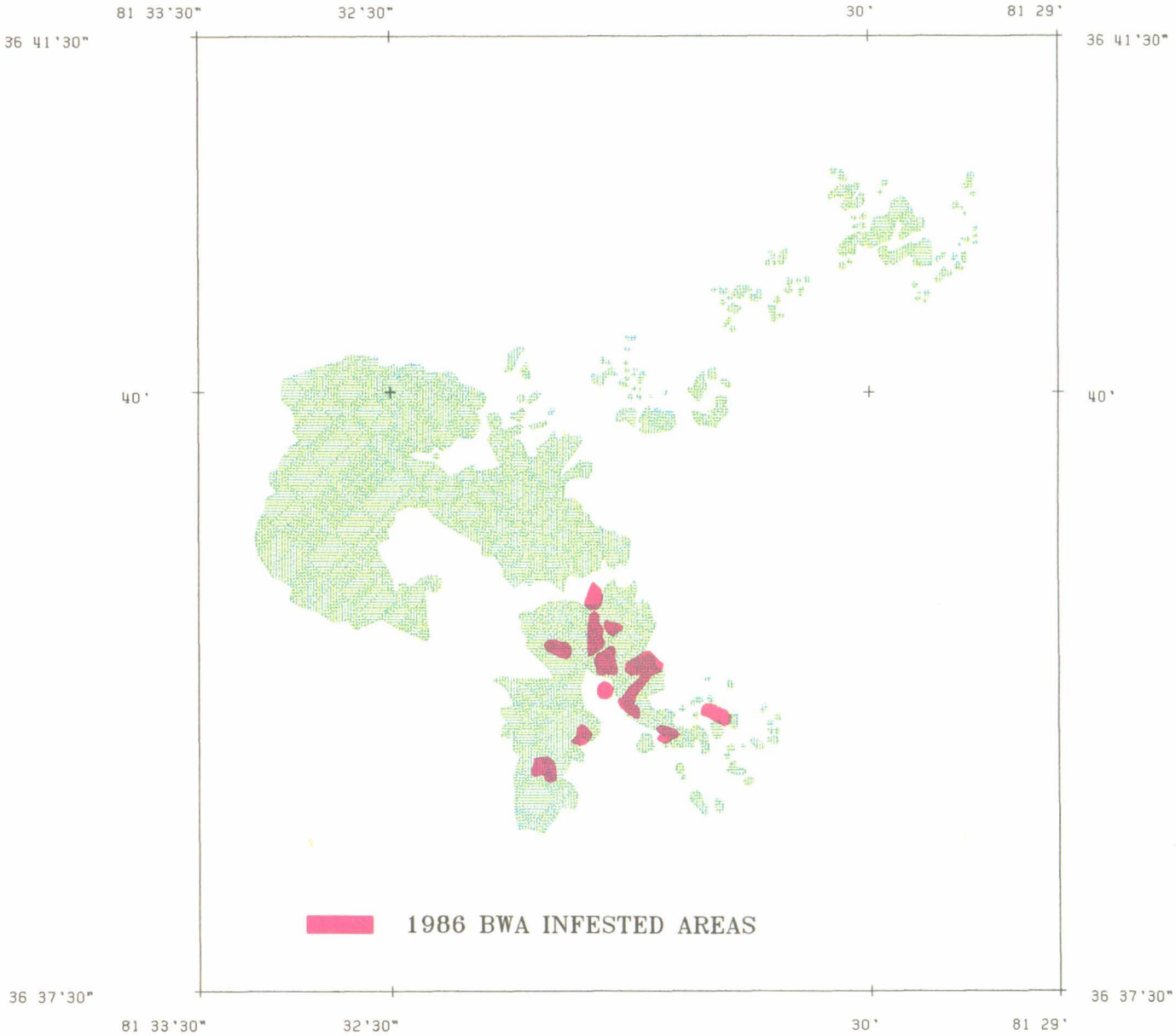


FIGURE 68 - 1986 BWA INFESTATION, MT. ROGERS

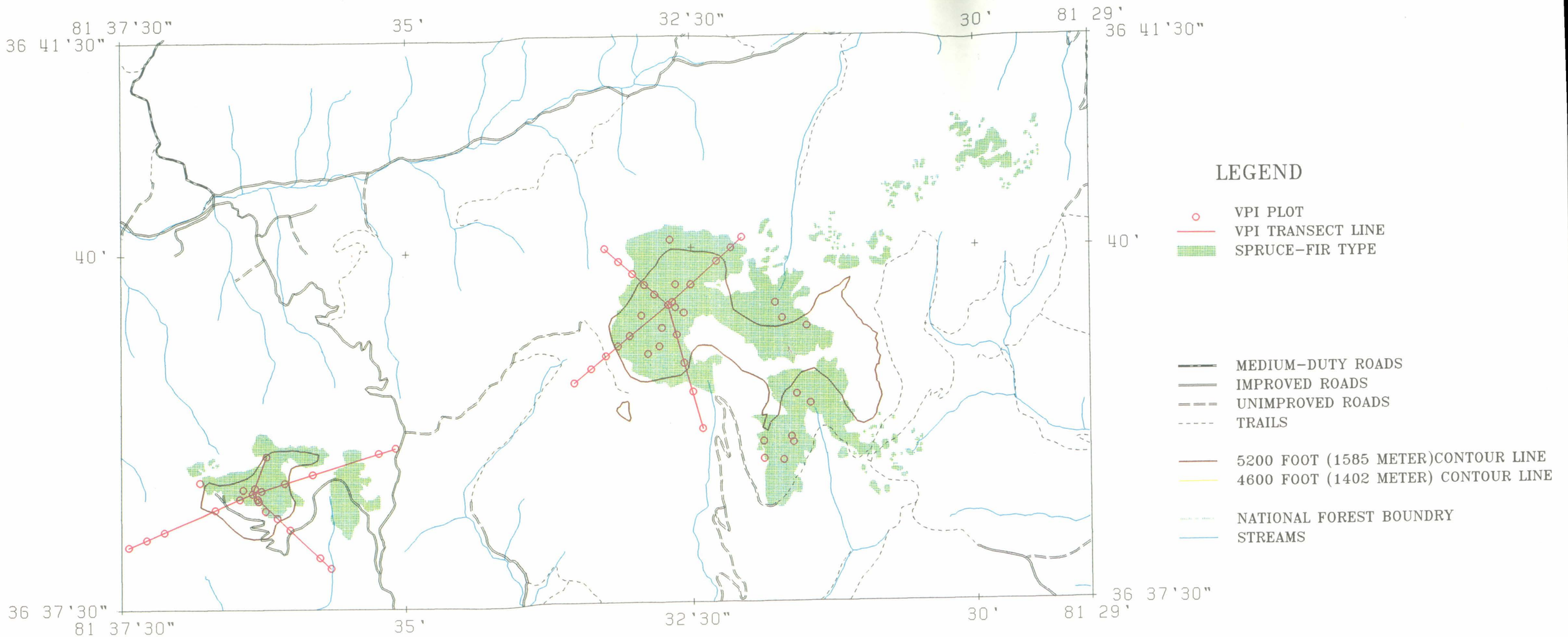


FIGURE 69 – STUDY PLOT LOCATIONS, MT. ROGERS AND WHITETOP MTN.

CONCLUSIONS

An attempt was made in this evaluation to use only well-established and documented procedures for assessing spruce-fir mortality. CIR aerial photography is considered the best current remote sensing alternative for operational surveys assessing forest decline. Computer assisted digital image analysis offers potential advantages over conventional aerial photo interpretation, especially in respect to the increasing resolution and availability of satellite data. However, the immediate requirements of the Spruce-Fir Research Cooperative, the National Vegetation Survey, and SARRMC required techniques that could be well defended and quickly implemented to provide baseline data to other investigators. Aerial photography obtained as a result of this project has been widely used by researchers studying spruce and fir in the southern Appalachian mountains.

Of the current approaches assessing the spruce-fir conditions in the southern Appalachians, a combined aerial photo-ground survey still seems to offer the greatest potential. Less structured ground surveys to accompany aerial photo interpreation may be worthy of consideration in future evaluations. The difficult access to many remote areas containing spruce-fir type in the southern Appalachians makes techniques used in this evaluation more attractive than methods using exclusively ground techniques. The advantages are especially evident if surveys are to be conducted at frequent intervals to obtain trend data.

The GIS provided the capability to store, analyze, and display the spatial data obtained from the aerial photography and ground surveys. This information was integrated with geographic information obtained from other data sources to evaluate spatial relationships. This project has produced maps to illustrate geographic relationships, but interactive displays on a CRT produce graphics which may be models of forces causing mortality in spruce-fir forests. The GIS data base implemented as a result of this evaluation should be used to compare the present spatial distribution of spruce-fir mortality with those obtained from future inventories. A GIS will provide the most efficient, and probably the only, means to analyze databases expanding time and physiographic regions.

Results were variable among geographic areas. In summary, the significant findings of the project were:

1. Spruce-fir type in the southern Apalachians occupied an area of 65,752 acres (26,610 ha) in six major geographic areas.

2. Overall, mortality was classified as: 24% severe, 6% heavy and 70% light.

3. Spruce-fir type was distributed by geographic areas as follows: 74% on Great Smoky Mountains National Park; 11% on the Black Mountains; and 10% on the Balsam Mountains. All other regions contained 2% or less of the total area.

4. The percentage of area classified as severe mortality increased with increasing elevation.

5. Red spruce mortality was not above levels usually expected in high-elevation forests, ranging from 3% on Roan Mountain to 14% on the Black Mountains.

6. Fraser fir mortality ranged from 44% on Roan Mountain to 91% on Great Smoky Mountains National Park. These high levels of mortality are the result of infestation by balsam woolly adelgid.

7. Patterns of mortality are primarily determined by changes in species composition of the stand. Fraser fir dominance increases with increasing elevation, reflecting greater mortality at higher elevations. These patterns are consistent with previous accounts of balsam woolly adelgid infestations.

8. Significant differences in mortality were not reflected by ownership distribution.

9. As reflected in the stand composition at different elevation strata, Fraser fir volume increased with increasing elevation while red spruce volume decreased with increasing elevation.

10. Volume of dead Fraser fir increased with increasing elevation while dead red spruce volume was variable by elevation.

11. Excluding the introduction of the balsam woolly adelgid, disturbance histories influenced the pattern and extent of the current spruce-fir boundaries, but did not appear to impact the current mortality classifications.

12. On Mount Mitchell, a reduction during the past 30 years in total area occupied by the spruce-fir type has possibly occurred with the boundaries receding from lower to higher elevations.

Additional surveys are recommended to develop trends in relation to spruce-fir boundaries and distribution of mortality within the type. Development of the digital database should continue and be expanded to include other regions and update information in the southern Appalachians as it becomes available.

LITERATURE CITED

Adams, H. S.; Stephenson, J. L.; Blasing, T. J.; Duvick, D. N. 1985. Growth-trend declines of spruce and fir in the mid-Appalachian subalpine forests. Environmental and Experimental Botany. 25(4) :315-325.

Alberts, D.; Morse, B.; Niedzwiedek, H. 1987. MOSS family software development issues. In: Proc. third national MOSS users workshop. USDI. Denver, CO. 148-160 p.

Aldrich, R. C.; Drooz, A. T. 1967. Estimated Fraser fir mortality and balsam woolly aphid infestation trend using aerial color photography. Forest Science. 13:300-313.

Amman, G. D. 1961. Predator introduction for control of balsam woolly aphid on Mt. Mitchell, North Carolina. USDA Forest Service. Southeastern Forest Experiment Station. Res. Note 153. 2 p.

Amman, G. D. 1962. Seasonal biology of the balsam woolly aphid on Mount Mitchell, North Carolina. Journal of Economic Entomology. 55(1):96-98.

Amman, G. D. 1970. Phenomena of *Adelges piceae* populations (Homoptera: Phylloxeridee) in North Carolina. Ann. Entomol. Soc. Am. 63:1727-1734.

Amman, G. D.; Speers. C. F. 1965. Balsam woolly aphid in the southern Appalachians. Journal of Forestry. 63:18-20.

Amman, G. D.; Talerico, R. L. 1967. Symptoms of infestation by balsam woolly aphid displayed by Fraser fir and bracted balsam fir. Res. Note SE-85. USDA Forest Service, Southeastern Forest Experiment Station. 7 p.

Balch, R. E. 1952. Studies of the balsam woolly aphid, *Adelges piceae* (Ratz.) and its effects on balsam fir *Abies balsamea* (L) Mill. Canadian Department of Agriculture. Pub. No. 867. 76 p.

Barry, P. J. 1981. Status and post suppression evaluation of balsam woolly aphid infestation on Roan Mountain, Toecane Ranger District, Pisgah National Forest, North Carolina. Atlanta: USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Insect and Disease Management. Rept. No. 81-1-34. 10 p.

Barry, P. J.; Oprean, T. M. 1979. Evaluation of balsam woolly aphid on Roan Mountain, Toecane Ranger District, Pisgah National Forest. North Carolina. Atlanta: USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Insect and Disease Management. Rept. No. 79-1-12. 7 p.

Bruck, R. I. 1984. Decline of Montane boreal ecosystems in central Europe and the southern Appalachian mountains. TAPPI Proc. 1984:159-163.

Bruck, R. I. 1985. Boreal Montane decline in the southern Appalachian mountains: potential role of anthropogenic pollution. In: Air pollution effects on forest ecosystems. Proc. Symp. St. Paul, MN, May 8-9. 1985. 137-155 p.

Bruck, R. I. 1987. Spruce-fir decline in the southern Appalachian mountains three-year analysis. In: Proc. Southwide Forest Disease Workshop, 1987. 17 p.

Bryant, D. G. 1974. A review of the taxonomy, biology, and importance of the adelgid pests of true fir. Can. Environ., Forest Service, NFLD For. Res. Centre. No. N-X-lll. 50 p.

Chittenden, A. K. 1905. Forest conditions in northern New Hampshire. Bull. 55. Washington: USDA Bureau of Forestry. 99 p.

Ciesla, W. M. 1962. Operational survey of balsam woolly aphid infestations, Mt. Mitchell State Park, North Carolina. USDA Forest Service, State and Private Forestry, Forest Pest Management, Asheville, NC. Report No. 62-87. 4 p.

Ciesla, W. M.; Buchanan, W. D. 1962. Biological evaluation of balsam woolly aphid. Roan Mountain Gardens, Toecane District, Pisgah National Forest, NC. USDA Forest Service, State and Private Forestry. FPM Rept. 62-93.

Ciesla, W. M.; Dull, C. W.; McCreery, L. R.; Mielke, M. E. 1986b. Inventory of decline and mortality in spruce-fir forests of the eastern United States with CIR photos. In: Proc. ISPRS Comm. VII, Enschede, the Netherlands. 391-396 p.

Ciesla, W. M.; Furniss, M. M.; McGregor, M. D.; Bousfield, W. E. 1971. Evaluation of Douglas-fir beetle infestations in the North Fork Clearwater River Drainage, Idaho - 1971. USDA Forest Service, Northern Region. Missoula, MT. Insect and Disease Rpt. 71-46, 15 p.

Ciesla, W. M.; Lambert, H. L.; Franklin. R. T. 1963. The status of the balsam woolly aphid in North Carolina and Tennessee. USDA Forest Service, State and Private Forestry, Forest Pest Management. Asheville. NC. Rept. no. 1-11-63.

Ciesla, W. M.; Lambert, H. L.; Franklin, R. T. 1965. Status of the balsam woolly aphid in North Carolina and Tennessee - 1964. USDA Forest Service. State and Private Forestry, Zone 1, Forest Insect and Disease Control. Asheville, NC. Rept. 65-1-1.

Ciesla. W. M.; Hildenbrandt, G. 1986. Forest decline inventory methods in West Germany: opportunities for applications in North American Forests. USDA Forest Service, Forest Pest Management, Methods Application Group, Ft. Collins, CO. 31 p.

Ciesla, W. M.; Wilson. E. T.; Eav, B. B.; Ward, J. D. 1986a. Identification of red spruce and Fraser fir on large scale CIR aerial photos. USDA Forest Service, Forest Pest Management, Methods Application Group, Ft. Collins, CO. 21 p.

DeSelm, H. R.; Boner, R. R. 1984. Understory changes in spruce-fir during the first 16-20 years following death of the fir. In: The southern Appalachian spruce-fir ecosystem: Its biology and threats. Research/Resources Mgt. Rep. SER-71. White, P. S., ed. U.S. Department of Interior, National Park Service. 268 p.

Dull, C. W.; Clerke, W. H. 1983. Loran-C navigation as an aid to aerial photographic operations. Photogrammetric Engineering and Remote Sensing. 49 (10):1577-1584.

Eagar, C. C. 1978. Distribution and characteristics of basalm woolly aphid infestations in the Great Smoky Mountains. University of Tennessee, Knoxville. 72 p. M.S. Thesis.

Eagar, C. 1984. Review of the biology and ecology of BWA (balsam woolly aphid) on southern Appalachian spruce-fir forests. In: The southern Appalachian spruce-fir ecosystem: Its biology and threats. Research/Resource Mgmt.. Rep. SER-71. White, P. S., ed. National Park Service. 36-50.

Flavell, T. H.; Lambert. H. L. 1971. Status of the balsam woolly aphid in the southern Appalachians - 1970. Rep. No. 71-1-16. USDA Forest Service State and Private Forestry, Forest Pest Control, Asheville, NC. 13 p.

Ghent, J.; Covington, S.; Jennings, S.; Tolman, D. 1986. Evaluation of balsam woolly adelgid

on Mount Rogers National Recreational Area. Rep. No. 86-1-8. USDA Forest Service R-8, Forest Pest Management.

Griggs, R. F. 1946. The timberlines of Northern America and their interpretation. Ecology 27(4):275-289.

Groton, E. J. 1985. Assessment of Spruce-fir forests in the southern Appalachian mountains. Tennessee Valley Authority. Norris. TN. 77 p.

Haneman, D. M.; Lambert, H. L.; Johnston, D. D. 1981. Detection and evaluation of the balsam woolly aphid infestation on Mt. Rogers, Virginia. 1980. Rept. No. 81-1-12. USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Insect and Disease Management. 10 p.

Hart, A. C. 1959. Silvical Characteristics of red spruce. (Picea rubens). Stn. Pap. 124. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, PA. 22 p.

Hornbeck, J. W.; Smith, R. B. 1985. Documentation of red spruce growth decline. Canadian Journal of Forest Research. 15:1199-201.

Johnson, H. T.; Siccama, T. G. 1983. Acid deposition and forest decline. Environmental Science and Technology. 17(7):294-305.

Johnson, K. D. 1977. Balsam woolly aphid infestation of Fraser fir in the Great Smoky Mountains. University of Tennessee, Knoxville, TN. 64 p. M.S. Thesis.

Johnson, K. D. 1980. Fraser fir and the balsam woolly aphid: Summary of information. Southern Appalachian Research/Resource Mgt. Coop. Western Carolina University, Cullowhee, NC. 62 p.

Johnson, K. D.; Lambert, H. L.; Barry, P. T. 1980. Status and post suppression evaluation of balsam woolly aphid infestations on Roan Mountain, Toecane Ranger District, Pisgah National Forest. North Carolina. Rep. No. 80-1-13. USDA Forest Service, Southeastern Area. State and Private Forestry, Forest Insect and Disease Management. 9 p.

Klien, W. H.; Bennett, D. D.; Young, R. W. 1979. A pilot study to measure annual mortality of lodgepole pine caused by mountain pine beetle. Rep. 78-4. USDA Forest Service, Intermountain Region. Ogden UT and Methods Application Group, Davis, CA. 15 p.

Lambert, H. C.; Ciesla, W. M. 1966. Status of the balsam woolly aphid in North Carolina and Tennessee— 1965. USDA Forest Service, State and Private Forestry, Zone 1, Forest Insect and Disease Control. Asheville. NC. Report No. 66-1-1.

Lambert, H. L.; Ciesla, W. M. 1967. Status of the balsam woolly aphid in the southern Appalachians - 1966. Rep. No. 67-1-3. USDA Forest Service. State and Private Forestry, Zone 1, Forest Insect and Disease Management, Asheville, NC. 15 p.

Lambert, H. L.; Franklin, R. T. 1963. Balsam woolly aphid detection survey. Grandfather Mountains. Rep. No. 1-2-63. USDA Forest Service. Southeastern Area, State and Private Forestry, Forest Pest Control. Asheville, NC. 4 p.

Lambert. H. L.; Morgon, S. W.; Johnson, K. D. 1980. Detection and evaluation survey of the balsam woolly adelgid infestations on Mt. Rogers - Virginia, 1979. USDA Forest Service, Southeastern Area, State and Private Forestry. Forest Insect and Disease Management.

Lovett, G. M. 1984. Pollutant deposition in mountainous terrain. In: White. P. S., ed. The southern Appalachian spruce-fir ecosystem: its biology and threats. Research/Resource

Management Report SER - 71. U.S. Department of Interior, National Park Service. 26 p.

McCambridge, W. F.; Kowal, R. J. 1957. Forest insect conditions in the southeast during 1956. Paper 76. USDA Forest Service, Southeastern Forest Experiment Station. 7 p.

McLaughlin, S. B. 1985. Effects of air pollution on forests, a critical review. Journal of Air Pollution Control Association. 35:512-534.

McLaughlin, S. B.; Blasing, T. J.; Downing, D. J.; Cook, E. R.; Johnson, A. H.; Adams, H. S. 1986. Regional responses of red spruce to environmental stress. In: Third annual acid rain conference for the southern Appalachians. Tennessee Valley Authority. Gatlinburg, TN. 16-17 p.

Mielke, M. E.; Soctomah, D. G.; Marsden, M. A.; Ciesla. W. M. 1986. Decline and mortality of red spruce in West Virginia. USDA Forest Service, Forest Pest Management, Methods Application Group, Ft. Collins, CO. 26 p.

Nagel, W. P. 1959. Forest insect conditions in the southeast during 1958. USDA Forest Service. Stn. Paper SE - 100. 10 p.

Nicholas, N. S.; White, P. S. 1985. The effects of balsam woolly aphid infestations on fuel levels in spruce-fir forests at Great Smoky Mountains National Park. Research/Resources Mgt. Rep. SER - 74. U.S. Department of Interior. 24 p.

Pope. R. B. 1957. The role of aerial photography in the current balsam woolly aphid outbreak. For. Chron. 33:263-264.

Puritch, G. S. 1973. The toxic effects of fatty acids and their salts on the balsam woolly aphid, *Adelges piceae* (Katz.). Canadian Journal of Forestry Research. 5:515-522.

Pyle, C. 1984. Pre-park disturbance in the spruce-fir forests of Great Smoky Mountains National Park. In: White, P. S., ed. The southern Appalachian spruce-fir ecosystem, its biology and threats. Research/Resource Management Rep. SER - 71. Washington: U.S. Department of Interior, National Park Service. 115-130 p.

Pyle, C.; Schafale, M. P.; Wentworth, T. R. 1985. History of disturbance in spruce-fir forests of the SARRMC intensive study sites— Mt. Rogers National Recreation Area, Black Mountains, and Great Smoky Mountains. SARRMC— southern Appalachian spruce-fir ecosystem assessment project. 67 p.

Ragenovich, I. R. 1977. Evaluation of balsam woolly aphid on Roan Mountain, Toecane Ranger District, Pisgah National Forest. North Carolina. Rep. No. 78-1-2. USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Insect and Disease Management. 6 p.

Ramseur, G. S. 1960. The vascular flora of the high mountain communities of the southern Appalachians. Journal of Elisha Mitchell Science Society. 76:82-112.

Rauschenberger, J. L.; Lambert, H. L. 1968. Status of the balsam woolly aphid on Mt. Mitchell State Park, North Carolina— 1968. Rep. No. 68-1-1. USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Pest Control. Asheville, NC. 5 p.

Rauschenberger, J. L.; Lambert, H. L. 1969. Status of the balsam woolly aphid in the southern Appalachians— 1968. Rep. No. 69-1-29. USDA Forest Service, Southeastern Area. State and Private Forestry, Forest Pest Control. Asheville. NC. 19 p.

Rauschenberger, J. L.; Lambert. H. L. 1970. Status of the balsam woolly aphid in the

southern Appalachians— 1969. Rep. No. 70-1-44. USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Pest Control. Asheville, NC. 20 p.

Reiners, W. A.; Lang, G. E. 1979. Vegetational patterns and processes in the balsam fir zone, White Mountain, New Hampshire. Ecology. 60:403-417.

Rheinhardt, R. D. 1984. Comparative study of composition and distribution patterns of Subal/ pine forests in the Balsam Mountains of southwest Virginia and the Great Smoky Mountains. Bulletin of Torrey Botanical Club. 111(4):489-493.

Sakai, A. 1970. Mechanisms of desiccation damage of conifers wintering in soil-frozen area. Ecology. 51(4):657-664.

Saunders, P. P. 1984. Recreational impacts in the southern Appalachian spruce-fir ecosystem. In: White. P. S., ed. The southern Appalachian spruce-fir ecosystem: its biology and threats. Research/Resource Mgmt. Rep. SER-71. U.S. Department of Interior, National Park Service. 100-114 p.

Schofield, W. B. 1960. The ecotone between spruce-fir and deciduous forest in the Great Smoky Mountains. Durham, NC, Duke Univ. 176 p. Ph.D. Dissertation.

Scott, T. G.; Siccama, T. G.; Johnson, A. H.; Breisch, A. R. 1985. Decline of red spruce in the Adirondacks, New York. Bulletin of Torrey Botanical Club. 111:438-444.

Sheffield, R. M.; Cost, N. D. 1987. Behind the decline. Journal of Forestry. 85:29-33

Siccama, T. G.; Bliss, M.; Vogelman, H. W. 1982. Decline of red spruce in the Green Mountains of Vermont. Bulletin of Torrey Botanical Club. 109:162-168.

Smith, W. H. 1981. Air pollution and forests: Interactions between air contaminants and forest ecosystems. Springer—Verlag. New York. 379 p.

Smith, W. H. 1985. Forest and air quality. Journal of Forestry. 83:83-92.

Speers. C. F. 1958. The balsam woolly aphid in the Southeast. J. For. 56:515-516.

Stephenson, S. L.; Adams, H. S. 1984. The spruce-fir forest on the summit of Mount Rogers in southwestern Virginia. Bulletin of theTorrey Botanical Club. 111:69-75.

Stewart. C. A.; James, P. C.; Berisfield, W. E. 1982. A multistage sampling technique to assess root disease impact on the Clearwater and Nezperce National Forests, Idaho. Rep. 82-14. USDA Forest Service, Northern Region, Cooperative Forestry and Pest Management, Missoula. MT. 33 p.

Talerico, R. L. 1965. Examination of fir on Mt. Rogers for the balsam woolly aphid (Adelges piceae [Ratz.]) on the Holston Ranger District of the Jefferson National Forest. Rep. 65-52-8.USDA Forest Service, Region 7. Southern Insect and Disease Control, Harrisonburg, VA.

Thompson. M. M. 1966. Manual of photogrammetry. American Society Photogrammetry, Falls Church, VA. 1199 p.

U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, 1979. Aerial photography specifications. AP-300. Salt Lake City, UT, USDA. 41 p.

U.S. Department of Agriculture Forest Service. 1985. Insects of Eastern Forests. Miscellaneous Publication 1426. Washington: U. S. Department of Agriculture 608 p.

Ward, J. D. 1974. Status of balsam woolly aphid, *Adelges piceae* (Ratz.) on Roan Mountain, Toecane Ranger District, Pisgah National Forest. NC. Rep. No. 75-1-3. USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Insect and Disease Management. 12 p.

Ward. J. D.; Dull, C. W.; Ryan, G. W.; Remion, M. C. 1985. Estimating southern pine beetle caused timber losses over extensive areas. In: Proc. integrated pest management research symposium. Gen. Tech. Rep. S0-56. New Orleans: U. S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. p. 34-40.

Ward. J. D.; Wilson, E. T.; McDowell, W. M. 1973. Status of the balsam woolly aphid, *Adelges piceae* (Ratz). in the southern Appalachians, 1972. Rep. No. 73-1-35. Asheville, NC: USDA Forest Service, Southeastern Area, State and Private Forestry, Forest Pest Management. Asheville. NC.

Wear, J. F.; Pope, R. B.; Lauterbach, P. G. 1964. Estimating beetle killed Douglas fir by aerial photo and field plots. Journal of Forestry. 62:309-315.

Weiss, M. J.; McCreery. L. R.; Millers. I.; Miller-Weeks, M.; O'Brien, J. T. 1985. Cooperative survey of red spruce and balsam fir decline and mortality in New York, Vermont, and New Hampshire in 1984. NA-TP-11. U. S. Department of Agriculture, Forest Service, Forest Pest Management, Northeastern Area. Broomall, PA: 53 p.

Witter, J. A.; Ragenovich, I. R. 1986. Regeneration of Fraser fir at Mt. Mitchell, North Carolina, after depredations by the balsam woolly adelgid. Forest Science. 132 (3): 585-594 p.

White, P. S. 1984. The southern Appalachian spruce-fir ecosystem, an introduction. In: White, P.S., ed. The southern Appalachian spruce-fir ecosystem: its biology and threats. Research/Resources Mgt. Rpt. SER - 71. Washington: U.S. Department of Interior, National Park Service. 21 p.

Whittaker, R. H. 1956. Vegetation of the Great Smoky Mountains. Ecology Monograph. 26: 1-80.

Standing dead spruce and fir along the Blue Ridge Parkway in the Black Mountains.

SD11
U596.3
No. 13

EVALUATION OF SPRUCE AND FIR MORTALITY IN THE SOUTHERN APPALACHIAN MOUNTAINS

Protection Report R8-PR 13 October, 1988